Office of Experiment Stations,
Irrigation and Drainage Investigations,
Cheyenne, Wyoming.

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United States Department of Agriculture,

OFFICE OF EXPERIMENT STATIONS,

A. C. TRUE, Director.

LIST OF PUBLICATIONS OF THE OFFICE OF EXPERIMENT STATIONS ON IRRIGATION.[1]

FOR GRATUITOUS DISTRIBUTION.

(Requests for these publications should be sent to the Secretary of Agriculture or to a Senator or Representative in Congress.)

Irrigation in Humid Climates. By F. H. King, Professor of Agricultural Physics, College of Agriculture, University of Wisconsin, and Physicist of the Wisconsin Agricultural Experiment Station. Pp. 27, figs. 4. (Farmers' Bulletin No. 46, Office of Experiment Stations.)

Treats of the advantages of an abundant supply of soil moisture, the rainfall of the growing season in the United States, water as a plant food, the advantages and disadvantages of irrigation in humid climates, extent of irrigation in the humid parts of Europe, the rainfall of Europe and the Eastern United States, the character and antiquity of European irrigation, fertilizing value of irrigation waters, lines along which irrigation should first develop, land best suited to irrigation in humid climates, waters best suited to irrigation, amount of water needed for irrigation, methods of obtaining water for irrigation, the construction of reservoirs, and methods of applying water.

Irrigation in Fruit Growing. By E. J. Wickson, M. A., Professor of Agricultural Practice, University of California, and Horticulturist of the California Experiment Station. Pp. 48, figs. 8. (Farmers' Bulletin No. 116.)

A statement of the relations of irrigation to fruit production, and of irrigation methods, as they have been demonstrated by Pacific coast experience.

Rise and Future of Irrigation in the United States. By Elwood Mead, Expert in Charge of Irrigation Investigations, Office of Experiment Stations. Pp. iii, 591-612, pls. 5. (Reprint from Yearbook, 1899.)

A popular discussion of this subject under the following heads: Remains of ancient irrigation works; early irrigation in California; beginnings of modern irrigation; cooperative colonies in Colorado and California; corporate canal building and objections to such canals; water-right problems of the arid regions; the appearance and resources of the arid region; present and future of irrigation, including growth of irrigation and need of better laws, need of reform in the management of arid public land, influence of the range industries, uncertainty as to State and Federal jurisdiction, complications from lack of uniform water laws, methods and measures needed to develop the arid region, appropriation and distribution of the water supply, public supervision and control of irrigation, and influence of irrigation upon people and country; and the commercial importance of irrigation.

[1] The irrigation investigations of the Department are under the immediate supervision of Prof. Elwood Mead, Irrigation Expert in Charge, Cheyenne, Wyo.

FOR SALE.

secure these publications, address the Superintendent of Documents, Union Building, Washington, D. C., inclosing price given. Remittances must be made by cash or United States postal order. Postage stamps and checks not accepted.)

otes on Irrigation in Connecticut and New Jersey. By C. S. Phelps, B. S., and Edward B. Voorhees, M. A. Pp. 64, figs. 7. (Bulletin No. 36, Office of Experiment Stations.) Price 5 cents.

This bulletin discusses the need, methods, and history of irrigation in Connecticut, irrigation plants in use in Connecticut, experiments on the effects of rrigation on strawberries and suggestions regarding irrigation, the need of rrigation in New Jersey, amount of water necessary, storage of water, seepage, ost of irrigation, areas capable of being watered by gravity, irrigation by umping, irrigation by wells, warping, water meadows, total area irrigable, stimated cost of irrigation and suggestions for small plants, use of irrigation n New Jersey, possibility of pumping large quantities of water from wells for rrigating purposes, and irrigation experiments in New Jersey.

Water Rights on the Missouri River and Its Tributaries, by Elwood Mead, State Engineer of Wyoming. With papers on the Water Laws of Colorado, by John E. Field, State Engineer; and of Nebraska, by J. M. Wilson, State Engineer. Pp. 80, maps 3, figs. 4. (Bulletin No. 58, Office of Experiment Stations.) Price 10 cents.

A discussion of the irrigation laws which control the diversion and use of ater from the Missouri River and its tributaries. The region covered in this scussion includes Colorado, Kansas, Montana, Nebraska, North Dakota, South akota, Wyoming, and the Northwest Territories of Canada.

bstract of Laws for Acquiring Titles to Water from the Missouri River and Its Tributaries, with the Legal Forms in Use. Compiled by Elwood Mead, State Engineer of Wyoming. Pp. 77. (Bulletin No. 60, Office of Experiment Stations.) Price 10 cents.

Includes abstracts of laws and legal forms in use in Colorado, Kansas, Montana, Nebraska, South Dakota, Wyoming, and the Northwest Territories of anada.

Water-Right Problems of Bear River. By Clarence T. Johnston and Joseph A. Breckons. Pp. 40, pls. 9. (Bulletin No. 70, Office of Experiment Stations.) Price 15 cents.

Presents some of the water right complications of interstate streams as llustrated on Bear River. The bulletin discusses the water supply of the river nd its diversion and the controversies which have arisen regarding water rights nd the need of uniform laws.

rrigation in the Rocky Mountain States. By J. C. Ulrich. Pp. 64, pls. 10. (Bulletin No. 73, Office of Experiment Stations.) Price 10 cents.

Explains the agricultural conditions prevailing and the methods of acquiring nd using water for irrigation practiced in that portion of the arid region covred more particularly by the States of Colorado, Wyoming, Utah, Idaho, and Iontana, in which the conditions and methods are somewhat similar.

he Use of Water in Irrigation in Wyoming and Its Relation to the Ownership and Distribution of the Natural Supply. By B. C. Buffum, M. S., Professor of Agriculture and Horticulture, University of Wyoming, and Vice-Director of Wyoming Agricultural Experiment Station. Pp. 56, pls. 8. (Bulletin No. 81, Office of Experiment Stations.) Price 10 cents.

This bulletin reports experiments on the duty of water for different crops in Wyoming, and discusses the application and measurement of water, conditions affecting the duty, and continuous flow as a basis of appropriation.

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U. S. DEPARTMENT OF AGRICULTURE.

FARMERS' BULLETIN No. 46.

IRRIGATION IN HUMID CLIMATI

BY

F. H. KING,

Professor of Agricultural Physics, College of Agriculture, University of Wisconsi
and Physicist of the Wisconsin Agricultural Experiment Station

UNDER THE SUPERVISION OF THE OFFICE
OF EXPERIMENT STATIONS.

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ILLUSTRATIONS.

phosphates and silicates of the soil, setting free the phosphoric acid, potash, lime, and magnesia compounds without which no plant is able to mature its fruit.

(3) They carry atmospheric nitrogen into the soil, and thus help replace the nitrogen which is constantly running to waste in the drainage waters or escaping back into the air.

(4) Coming from the warm air and soaking through the hot surface, they carry deeper into the soil the warmth which makes the root action of plants more powerful, cause the phosphates and potash to be dissolved more readily, and greatly stimulate the production of available nitrogen compounds by the microscopic organisms which abound in the soil.

(5) Then, again, rains, as already explained, carry small amounts of nitrogen compounds with them to the soil, and most natural irrigation waters, in addition, contain some potash, phosphoric acid, and considerable quantities of lime, magnesia, and sulphuric acid.

It is not strange, therefore, that an abundance of warm, sweet water applied to fields at opportune times and retained there by judicious and thorough tillage enables even poor soils to bring forth large yields.

It is the possibility of supplying an abundance of water to the soil at the right time which makes irrigation farming so much more certain and the average yields so much larger than obtain under the ordinary conditions and methods of humid climates.

The plant feeding and growing in the soil is like the animal comi to maturity and fattening in the stable—it can not at any stage rece a serious check to its growth and come out at the end of the seas with that vigor and total product which result where no hindra intervenes.

Just as soon as the amount of soil moisture in the surface foot crop-bearing field falls below a certain percentage, the soil's abil supply food is decreased and the growing crop soon reaches a where it is not furnished with plant food as fast as it demands inevitable result being a diminished rate of growth and ul starvation.

THE RAINFALL OF THE GROWING SEASON IN THE UNITED IS INSUFFICIENT FOR MAXIMUM YIELDS.

Those seasons are very rare indeed in most parts of the Unit which bring to the soil a supply of rain adequate to permit mum amount of plant food to be elaborated in it or to be rem it by growing crops.

It is almost invariably true that as a crop advances towar its spread of leaf surface becomes so great that the loss of the surface soil through the plant is much more rapid tha water from below and the fall of rains from above are able t result being a reduction of the rate of plant growth.

The writer has succeeded in growing, under field conditions, on one-eighteenth of an acre, more than 14.5 tons of water-free substance in flint corn and 83.5 bushels of kiln-dried shelled corn per acre by supplying all the water which the plants could use and at the right time. Under similar conditions common red clover yielded over 4 tons of hay in the first crop. The second crop on the same land exceeded 2 tons per acre, while the third growth was heavy and 6 to 8 inches high. It should be said, too, that these results were obtained without the aid of manure or fertilizers of any sort, that the water used was pumped from an ordinary lake, and that the land was a clay soil in only fair condition.

Potatoes have been grown in pots holding 500 to 600 pounds of soil, so arranged that they could be weighed at any time and an exact knowledge of the amount of soil moisture present ascertained; and yields as high as 695 bushels of tubers to the acre have been secured, using 24 inches of water, which is more than falls during the growing season of this crop in Wisconsin. Flint corn under similar conditions was made to produce at the rate of 17⅓ tons of water-free substance per acre; but to do this it required 34¼ inches of water, an amount which more than equals the mean rainfall for the whole year; and it is certain that had a less quantity of water been used the crop would have been smaller.

WATER ONLY ONE OF THE NECESSARY PLANT FOODS.

It is not at all strange that the ancient Egyptian and Grecian philosophers, with their lack of exact knowledge and under their arid climatic conditions, should have come to believe that water is the sole food of plants; nor that this opinion should have been held until nearly the beginning of the eighteenth century. As a matter of fact, water does contribute more than half of the material which makes up the dry matter of plants, and as water it constitutes from three-fourths to more than nine-tenths of their green weight.

But while these are the facts, and while it is true that abundant and timely rains do make comparatively poor soils produce large yields, it must not be inferred that with ample and timely supplies of water applied to the soil, all else may be neglected and the hope entertained that any agricultural soil will thus be held up to a high state of productiveness for an indefinite term of years.

It is a matter of universal experience that sewage waters, not contaminated with poisonous compounds and not too concentrated, cause land to give much larger returns than river, lake, or well water. The writer learned, while visiting the celebrated Craigentinny meadows near Edinburgh, that the purchasers of the grass from those lands are very particular to specify, as a condition of their purchase, that their grass shall be watered with the day sewage, which contains a higher percentage of soluble and suspended organic matter than that of the night; and they are also particular to stipulate that they shall have the first rather

than the second or third use of the water, knowing that water which has passed over a cultivated field or meadow has lost something of its fertilizing value.

It is claimed also by the owners and renters of water meadows in the south of England, where the irrigation is directly from the streams, that that land which received the water first was most benefited by it. It is true that there are those who claim that on their lands the second and third waters are as good as the first, but this is probably due to the presence in those particular soils of an abundance of the substances carried by the waters.

It is impossible to overestimate the importance of water as a plant food. It is indispensable, and is used more than any other substance. It must be borne in mind, however, that water is not usually a complete plant food.

ADVANTAGES AND DISADVANTAGES OF IRRIGATION IN HUMID CLIMATES.

Where irrigation waters can be economically applied to lands it has some important advantages in crop production over the natural rainfall, even where that is large. In the first place, irrigation waters can be applied at such times and in such quantities as they are needed, and this gives a certainty to results which is impossible where the outcome must depend upon the chances of adequate or inadequate, timely or untimely, rainfall.

Where the natural rainfall must be depended upon it is imperative that only so many plants be allowed to occupy the soil as are likely not to increase the loss of soil moisture beyond what the rains and tillage will make good, whereas by irrigation methods the closeness of stand upon the ground is limited only by the demands for root room, air, and sunshine. Since many more plants can be grown upon an acre by irrigation than otherwise, the yield will be much larger; because, no matter how much we may crowd a plant by feeding, there are inherited limits of stature beyond which we may not hope to pass, and a few plants, even if of abnormal proportions, can never equal in aggregate yield a large number of individuals of normal stature.

Then, too, waters used for irrigation contain almost without exception much larger percentages of both the organic and the ash ingredients of plant food than rain waters do, and, as this is largely in the soluble form, it becomes at once available, and thus stimulates vigorous growth.

Setting matters of expense aside in this consideration, there are disadvantages and dangers attending irrigation in humid climates which should not be lost sight of by those who are thinking of adopting this practice.

It not infrequently happens in arid countries that inexperienced men apply so much water that the soil is water-logged and the crops injured

or destroyed. In humid climates there is the additional danger of heavy or protracted rains following immediately upon the thorough irrigation of a field. From this it follows that all lands in humid climates intended for irrigation must be thoroughly drained, either naturally or by artificial methods.

It may be said, however, that the danger of water-logging soils by irrigation is not as much greater in humid than in arid regions as many appear to think. On account of the tendency of all heavy soils to puddle and bake after they have been thoroughly saturated with water, and because the surface soils are inevitably brought into this condition on considerable portions of the field—if not over its whole area—where irrigation is practiced, while this only rarely occurs after natural rainfalls, it follows that in this respect irrigation waters are not as good as the natural rains. Where the soils are sandy and light, however, the danger in this direction is greatly reduced or entirely disappears.

While the amount of water available for purposes of irrigation in humid climates is much larger than it is in arid regions, there is, nevertheless, not enough to irrigate all farming lands were that desirable, and while it is true that thorough and careful irrigation in most parts of the United States east of the one hundredth meridian would more than double the average yield per acre of almost all crops now raised, it can not be said that the time has yet come when it is desirable to use all available water for purposes of irrigation.

We are yet a long way from having exhausted our resources in the direction of improved methods of tillage which shall conserve and turn to better account the waters which fall as rain. Moreover, the density of population is not yet great enough to consume the increased product which would result from thorough irrigation to the extent which the available water would permit.

But while the time is not ripe for the Middle, Eastern, and Southern States to apply methods of irrigation in any general way or on an extensive scale, we have, nevertheless, reached a point where a very large number of people who are favorably situated with reference to water, soil, and market can well afford to think about developing irrigation plants upon their lands, and this is especially true if the farm is not large enough to fully occupy the available time and energies of its owners by the ordinary methods.

EXTENT OF IRRIGATION IN THE HUMID PARTS OF EUROPE.

The writer had an opportunity in the summer of 1895 to visit and study irrigation districts in various parts of Scotland, England, France, Italy, Switzerland, Germany, Holland, and Belgium. While it can not be said that the art of irrigation is practiced generally in any sections of Europe except near the borders of the Mediterranean Sea, yet the total acreage is large. Wilson,[1] in speaking of the extent of irrigation,

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[1] Manual of Irrigation, p. 1.

places the acreage of Italy at 3,700,000, which is approximately 1 acre in every 16 of the total area. In Spain 500,000 acres are said to be irrigated, and in France 400,000 acres, which, in round numbers, is 1 acre to every 245 in Spain and 1 in every 321 in France. The writer has not access to the literature which would enable him to verify these statements, and, judging from impressions gained while traveling, they seem too high; but, however this may be, there is without doubt a very large acreage of irrigated lands in these countries.

THE RAINFALL OF EUROPE AND THE EASTERN UNITED STATES COMPARED.

If we compare the rainfall of Europe, exclusive of Russia, with that of the United States east of and including Minnesota, Iowa, Missouri, and Arkansas, we shall find that Europe has a mean precipitation ranging from 24 to 40 inches, and that the portion of the United States in question has a rainfall ranging from 26 to 55 inches. Eastward from and including Michigan and Indiana the precipitation for the year amounts to from nearly 36 to 50 inches, while south of Tennessee and North Carolina it ranges from 43 to 67 inches. It is true that in the Pyrenees and in the Alps and on the coast of Norway the yearly precipitation is greater than that stated above, but with these exceptions the total rainfall of western and southern Europe is very materially less than that of the eastern United States, the difference ranging from 2 inches to more than 16 inches per annum.

It should be stated, too, in connection with this larger rainfall in the United States as compared with that of Europe, that the seasonal distribution with us is unusually favorable to crop production, for we get the least in the three winter months and the most in the three summer months, when there is greatest need for it.

The seasonal precipitation in the humid portion of the United States is approximately as follows: For the three winter months it ranges from 3.5 inches in the West to 18 inches in the East or South; in the spring the range is from 8.5 inches to 22 inches; in summer from 11 inches to 24 inches, and in autumn the range is from 6 inches in the West to 20 inches in the South and East.

It would appear from what has been said regarding the difference between the rainfall in the United States and that in Europe that ther will be less occasion to irrigate here than there, and this, in a consi erable measure, is true, especially when reference is had to the Atlant and Gulf States.

It must be borne in mind, however, that while our total rainfal larger than that of Europe our mean summer temperature and t amount of sunshine are both higher, and the air, as a rule, is also moist, and that under these conditions the water is lost more ra by evaporation than under the conditions which prevail in the gr part of Europe.

In Italy, where irrigation is most generally and systematically practiced, the mean annual rainfall is about 37 inches, and of this amount 28 inches fall during the seven months which are suited to irrigation.

THE CHARACTER AND ANTIQUITY OF EUROPEAN IRRIGATION.

If we leave out of view sewage irrigation as practiced in the vicinity of large cities, it must be said that north of Italy and southern France nearly the whole of irrigation effort is devoted to raising hay and grass for soiling and pasture. This is particularly true of England, Holland, and portions of Germany and of the mountainous parts of France and Switzerland. It should also be noted here that in those Alpine districts where the rainfall is largest irrigation is most general, not because it is most needed there, but because it is more readily and cheaply secured than elsewhere, and because it pays.

In the south of France irrigation is extensively applied to olive and almond orchards, and the same is true of parts of Italy. In the Po Valley, naturally fertile but made more so by thorough and very systematic irrigation, water is artificially applied to almost all crops. Corn is here very extensively raised by irrigation. To convey some idea of the extent of this work, it may be stated that on August 7, 1895, while riding from Turin to Milan, the writer noted between Chivasso and Santhia, a distance of 18.5 miles, the irrigation of 100 fields of maize, ranging in size all the way from 4 to 20 acres. Wheat, barley, rice, and hemp, as well as rye grass and clover, are among the ordinary field crops which are extensively irrigated in the Po Valley. So, too, very extensive mulberry orchards are grown, the trees usually being set along the main and distributing canals, while the space between them is occupied by various kinds of farm crops.

The art of irrigation as practiced in European countries is not new. Two large canals in Lombardy which irrigate 250,000 acres were dug as long ago, Marsh tells us, as the twelfth century, while earlier still, at the time of the invasion of the Moors, very extensive systems of irrigation were introduced into Spain and southern France.

In England, too, the water meadows are so old that no one appears to know by what people they were introduced. Indeed, the present occupants of these lands speak of them as having always been irrigated in this manner.

It will be evident, therefore, from these facts, that irrigation under the climatic conditions of Europe must possess some substantial merits or it would not have persisted through all these years; and since it has been so extensively developed under the humid conditions of Europe, there seems little reason to doubt that irrigation may be found remunerative within suitable limitations in that part of this country lying east of the one hundredth meridian.

FERTILIZING VALUE OF IRRIGATION WATERS.

In traveling from place to place in Europe it was a continual surprise to the writer to learn from those who were practicing irrigation that the fertility which the river waters added to the soil was regarded as the chief advantage derived from them; and so thoroughly grounded is this idea in many places that large volumes of water are run over the land during the winter season or whenever it is not occupied by a crop. Indeed, on the water meadows of England it is the practice to have the water running over them just as much as possible, and it is claimed that the longer it can be kept running during the winter, when the weather is not too frosty, the larger will be the crop of grass the following season.

As an example of the amounts and kinds of material which would be added to an acre of land where exceptionally pure river water is used to a depth of 24 inches, we have calculated from a chemical analysis of the water of the Delaware River[1] as follows:

Materials in 24 acre-inches of Delaware River water.

	Pounds.
Calcium carbonate	242.60
Magnesium carbonate	166.16
Potassium carbonate	31.74
Sodium chlorid	20.54
Potassium chlorid	1.86
Lime sulphate	35.48
Lime phosphate	26.14
Silica	93.34
Ferric oxid	5.60
Organic matter containing ammonia	117.62
Total	741.08

The average amounts of nitrogen compounds, as computed from the chemical analyses of the waters of twelve streams in New Jersey, are as follows:

Nitrogen compounds in 24 acre-inches of water from New Jersey rivers.

	Pounds.
Free ammonia	15.63
Albuminoid ammonia	81.12
Nitrates	772.67
Nitrites	0.86
Total	870.28

When it is observed that these analyses were all made from streams where the water is regarded as pure, it is plain that there is a consid erable foundation for the opinion held in European countries regardir the fertilizing of lands by irrigation.

In further illustration of the fertilizing value of the water of rive in humid climates, it may be said that the amount of materials held solution in the waters of the Mississippi and St. Lawrence rivers,

[1] Rpt. New Jersey Geol. Survey, 1868, p. 102.

North America, and the Amazon and La Plata, in South America, is such that the average of the four would yield 655.6 pounds of solid matter for every 24 acre-inches.

Goss and Hare[1] found from analyses of the water of the Rio Grande at different periods from June 1 to October 31 that 24 acre-inches of the water added to the soil (in sediment and water) about 1,075 pounds of potash, 116 pounds of phosphoric acid, and 107 pounds of nitrogen. The water of this river is unusually rich in sediment, 2 acre-feet furnishing 81,309 pounds.

Where lake waters are used for irrigation larger amounts of fertilizing materials will usually be applied to the land than in the case of river waters, because in the lakes the salts are concentrated by evaporation.

Where there are such considerable quantities of plant food dissolved in river waters as the figures cited show, it must be evident that the fertilizing value of such waters is not inconsiderable. It is more valuable, too, pound for pound, than solid commercial fertilizers which we buy, because it is already in solution and ready to be taken up immediately and by all rather than a few roots of a crop to which the water is applied.

The water meadows of England have been in constant service as such, without rotation, and without the application of barnyard manure or commercial fertilizers of any kind, from time out of mind, perhaps during 150 or possibly 300 or 500 years, and yet they are said to be as productive to-day as they ever were. Sometimes the meadows are pastured by sheep being hurdled upon them very early in the spring before there is danger of fluke rot, and by cattle late in the fall, but except this the products of the land are yearly taken from them and never returned in the form of manure.

As a matter of fact, these water meadows are made to catch and fix again, and at once, the nitrates, potash, and phosphoric acid which are carried by the drainage waters from the higher lands, converting them into rich grass, which is fed to sheep and cattle, producing flesh and milk for the market or manure which is spread upon the higher lands.

It should be kept in mind, however, that the amount of water applied to these meadows is very large, probably each season many times the 24 acre-inches which we have used in the above estimate of the amounts of plant food which irrigation waters carry, and it is in this way that their high state of productiveness is maintained.

All farmers who own these lands esteem them very highly because (1) they are able to water them far more cheaply than they can haul manure upon them, even if it cost them nothing more than the hauling; (2) they are absolutely certain of a known amount of feed, and (3) with 20 or 40 acres of such land they are able to maintain a high state of productiveness on their unirrigated lands through the use of the manure made from the product of the meadows.

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[1] New Mexico Sta. Bul. 12.

LINES ALONG WHICH IRRIGATION SHOULD FIRST DEVELOP.

It has been pointed out that the time has not yet arrived for a full ;ilization of the water resources of the eastern United States for pur· oses of irrigation. There are certain lines, however, along which labor ,nd capital may be profitably invested, and some of these may now be nentioned:

(1) *The kitchen garden.*—There is no more important adjunct of the country home than the kitchen garden, nor can there be any question about the desirability of managing it in such a way that a high degree of productiveness shall be insured whether the season be wet or dry. The health of the family demands this, and the housewife who must plan for and secure the needed variety in three times 365 meals in the year should be expected to accept nothing less.

The only way to make these gardens a certainty in a very large part of even the humid portion of the United States is to apply irrigation to them. As these gardens should range from one-fourth of an acre to an acre and a half in area, the aggregate amount of land thus treated would be very large.

(2) *Market gardening.*—This is an industry in which a large income is expected from a small area, and because of this it is one upon which larger expenditures per acre are permissible, and in which curtailment of yield or injury to quality through drought is most disastrous. It is therefore a type of plant husbandry eminently suited to irrigation in humid climates.

(3) *Small-fruit culture.*—Strawberries, raspberries, and blackberries are all extremely sensitive to drought and much reduced in yield by a shortage in soil moisture, while the value of the crop per acre is so large that irrigation may be practiced with advantage where the rain-fall of early summer or the capacity of soil to hold water is small.

(4) *Cranberry culture.*—There is perhaps no crop raised in humid climates where the water conditions need to be under such complete control as for cranberries. Where the winters are severe the vines need to be largely submerged in water and so held until the killing frosts of spring are passed. Then it not infrequently happens th the vines must be flooded to avert the ravages of insects, or as a pr tection against frosts at or just before the time of harvest. It therefore be said that thoroughly successful cranberry cultur impossible where an abundance of water is not at command.

(5) *Dairy husbandry.*—Where the price of both lands and mil high and where an abundance of water can be had at a low cost, ca may find remunerative investment in the development of water me and in the production of corn for the silo and for soiling; for u thorough and judiciously applied system of irrigation the am coarse feed may be so much increased that the number of cows upon the land may be doubled.

LANDS BEST SUITED TO IRRIGATION IN HUMID CLIMATES.

The lands best suited to irrigation are those to which the water may be carried in large quantities by gravity and over relatively short distances, because these conditions will usually reduce the cost of water to the minimum. Moreover, the lands must not be so flat that there is difficulty in leading the water over the surface, nor so steep that it is difficult to prevent washing. It is possible to lead water over steep slopes, particularly if the lands are in grass, if proper care is exercised.

The lighter types of soil as a rule will be most benefited by irrigation in humid climates, not only because of the naturally small water capacity and consequent deficiency of water supply for large yields, but because such soils are less liable to be seriously injured in tilth by injudicious applications of water, and because they are generally unable, owing to their coarser grained structure, to yield as large amounts of plant food with the natural rainfall as the finer types of soil are capable of giving. It should be understood, however, that the heavier types of soil may be irrigated with profit where water is easily accessible and where thorough drainage is readily secured, although in these cases, except when the lands are in grass, great care must be exercised not to puddle the soil and not to allow it to dry and become cloddy.

WATERS BEST SUITED TO IRRIGATION.

It may be said, as a general rule, that the best waters for irrigation are those having the highest temperature and containing the largest amounts of suspended and dissolved mineral matter, provided the materials carried by the water are not injurious to plant life.

Without question the water of highest value for irrigation is the sewage of cities when it is adequately diluted and when it does not contain poisonous chemicals from the waste of factories. Sewage which is so turbid as to leave a coating of sediment upon the land is liable to work injury by clogging the pores in the surface soil and thus interfering with its proper aeration; but sewage of this character is the exception rather than the rule.

The amount of sewage discharged into streams and lakes is extremely large, and if irrigation in the humid sections of the United States is to be entered upon, it is important that attention should be directed to the fact that the utilization of sewage for crop production need not be limited to sewage farms, for a very large amount of sewage now is and will continue to be for a long time discharged into streams and lakes to run to waste. It will very often happen, particularly in the case of sewage-bearing streams, that irrigation plants may be so placed as to utilize these impure waters and, other conditions being equal, those lands which can be irrigated with this class of waters will pay the largest interest on the money invested. In arranging, therefore, to take the water out of such streams care should be taken to so place the intake

below the city or town that it may draw upon the most impure water which passes. It will even be practicable in some cases to divert the sewage-bearing portion of the stream to one side and thus prevent it from becoming unnecessarily diluted before reaching the point where it is to be used.

Next in value to warm sewage waters stand those which are muddy or which carry in suspension a large amount of sediment, and there are no soils upon which such waters will be more helpful than upon those which are coarse and sandy, for in these cases the fine silt will help to improve the texture and greatly increase the water-holding power. Aside from this effect of silt upon sandy lands, the amount of fertilizing ingredients which it contains is very large, and hence such water is valuable upon any land suitable for irrigation. This being true, it will often be found desirable to irrigate certain lands in the winter, and particularly early in the spring, when the river water is turbid, even though the land may already be saturated with water.

There are very many sections of country where the topography is abrupt and hilly, and particularly when ravines lead through fields, where it would be possible, by a system of broad, wattle-like ridges not high enough nor abrupt enough to seriously interfere with tillage, to so check the surface washing of fields as not only to prevent gullying, but at the same time to retain the water and the fertility which would otherwise pass from the fields into the streams.

While, therefore, the most impure waters are likely to prove best for irrigation it is nevertheless true that the purest and softest of waters will be found very helpful when used under favorable conditions. There are occasionally some natural waters which are positively injurious when applied to the land. These usually issue from peaty or boggy swamps. The injurious properties of these waters are due to the sulphate of iron which they contain.

AMOUNT OF WATER NEEDED FOR IRRIGATION.

The amount of water needed for irrigation varies within wide limits, being affected by the climate, weather, kind of soil, variety of crop, manner of application of the water, and by the character of cultivation which the field receives subsequent to irrigation.

Let us first consider the amount needed for a single watering. This must be determined by the amount of water the soil contains at the time it is to be irrigated and by the amount it should contain in order that plants may do their work to the best advantage.

The maximum capacity of upland field soils for water ranges fr about 18 per cent of their dry weight for the light sandy types to ab 30 per cent for the heavy clayey varieties, while the amounts of wa these soils should contain in order that plants may thrive in them b is from 12 to 14 per cent for the former and from 18 to 20 per cent the latter. The growth of plants will be seriously checked in s

soils when the water content falls below 8 per cent, and in heavy, clayey types when it falls below 14 per cent of the dry weight of the soil.

The dry weight of a light sandy soil and subsoil will average about 105 pounds per cubic foot, and the heavy, clayey type about 80 pounds per cubic foot. Hence the maximum amount of water per cubic foot of soil would be about 24 pounds for the clay and 18.9 pounds for the sand. This being true, 4.6 inches of water on the level would completely saturate the surface foot of heavy clay soil, were it entirely dry to begin with, while 3.6 inches would place the sandy soil in a similar condition.

But since water should be applied as soon as the water content of the sandy soil falls to 8 per cent and that of the clayey soil to 14 per cent, it follows that under these conditions 10.5 pounds of water, or 2 inches, is the maximum amount which would be needed to fill the surface foot of sandy soil and 12.8 pounds, or 2.46 inches, is enough to fill the surface foot of clay soil.

If we consider the second foot of soil to have been dried out to a corresponding extent, and that it is desirable to saturate this with water also, then the amounts just stated would need to be doubled, 4 inches being demanded for the sandy soil and 4.92 inches for the clayey soil. It is quite certain, however, that such an application of water to a field at one time would result in the percolation of a considerable amount of this water below the depth of root action, and hence in a considerable loss of it unless a large crop were growing upon the land at the time. It appears, therefore, that the amounts of water which may be applied to a field at one time will lie between 2 and 5 inches in depth over its whole surface.

How often this watering may need to be repeated it is not possible to state in anything like definite terms, but practical experience shows that as a rough average the intervals between watering where maximum yields are sought can not much exceed 7 to 14 days, the time being shortest when the crop is making its most vigorous growth.

In experiments at the Wisconsin Station during 1895 corn was irrigated once about every 7 to 9 days, applying at each time 4.43 inches of water. The corn, however, was planted very thickly upon the ground, the rows being only 30 inches apart and the hills 15 inches apart in the row, with from 2 to 5 stalks in each hill. The first irrigation was given June 26 and the last August 15, the total amount of water applied being 26.6 inches. The yield produced was 11,125 pounds of water-free substance per acre.

In the case of the water meadows of Europe very little attention is paid to the natural rainfall, the irrigation waters being applied whenever it is possible to do so, and whatever rains fall are counted as so much additional gain. It is true, however, that on most lands with crops other than grass attention would have to be given to the natural rainfall in the application of water by irrigation lest oversaturation of the soil and a positive waste of water should occur.

If it is regarded that ample irrigation has been provided when 2 inches of water is supplied every 10 days as a minimum and 4 inches as a maximum, then to meet this demand there would be required for 1 acre a continuous flow of water at the rate of 0.5042 cubic foot, or 3.77 gallons, per minute for 2 inches and 1.008 cubic feet, or 7.54 gallons, per minute for 4 inches. An area of 10 acres would require a rate of flow 10 times as rapid, or 5.04 cubic feet per minute for the minimum and 10.08 for the maximum.

These amounts of water expressed in cubic feet and in gallons are as follows:

	Cubic feet.	Gallons.
For 1 acre 2 inches deep,	7,260 =	54,310
For 1 acre 4 inches deep,	14,520 =	108,620
For 10 acres 2 inches deep,	72,600 =	543,100
For 10 acres 4 inches deep,	145,200 =	1,086,200

If these amounts of water are stored in circular reservoirs with vertical sides and 3 feet deep their diameters will be, respectively, 55.5 feet, 78.6 feet, 175.5 feet, and 248.5 feet.

METHODS OF OBTAINING WATER FOR IRRIGATION.

LEADING OUT WATER FROM STREAMS.

The simplest and most usual method of obtaining water for purpo of irrigation is to lead it out from streams. This is done by cuttin ditch or canal along the highest portion of the river valley over w the water can be led in the direction of the general fall or slope o country, and in valleys where the fall is large it is possible to le water off to such distances that extensive areas may be thus su with water.

HOLDING AND DIRECTING STORM WATERS.

In other cases the storm waters are utilized before they ha time to reach the main water ways. This is done by constructi and reservoirs at points where several ravines or draws join, th ing the water back, either to be used later in the season as d led out at once upon meadow lands, obliging it to drain t flow so slowly over them that most of the fertility, whether s or dissolved, is deposited upon or in them. Extensive areas irrigated in the southwest of England and in the hilly and mo parts of France, Switzerland, Italy, and Spain.

LEADING OUT THE UNDERFLOW FROM HIGHER LANDS.

There are many localities, especially in hilly countries, ar along the side of a river valley, where a terrace rises to height above the flood plane from which water is continuo oozing from the ground, and to such an extent as to keep unfit for agricultural purposes. In many such cases the led out by underdraining upon lower lands and stored t become warm, and then applied to the surface for irriga time rendering the land from which the water has be for cultivation.

Besides the deeper artesian waters which are available in many localities for irrigation purposes, there are a larger number of localities where "flowing wells" of the artesian type may be had and their waters used for the irrigation of small areas. In these cases the water may often be raised to a height of several feet above the ground and thence led away to where it would be valuable for irrigation in either a kitchen or market garden. Often such wells will supply the equivalent of a 1-inch stream flowing 4 miles per hour, which is water enough to irrigate to a depth of 4 inches every 10 days 2.42 acres of land, or about 5 times the area a 3-inch piston with a 12-inch stroke will control when working 8 hours a day and making 30 strokes a minute.

LIFTING WATER BY ITS OWN POWER

Where the beds of streams lie below the level of the area which it is desired to irrigate it becomes necessary to employ lifting devices of one

FIG 1 Water wheel at Baiersdorf, Bavaria

form or another in order to bring the water to a level at which it can be led over the land, and there have been invented various devices by which a portion of the energy of a stream is turned to use in lifting another portion of the stream to a height at which it may be utilized for irrigation.

Where the stream is large in proportion to the water which it is desired to lift, and where the height to which the water must be raised

is not great, a very old device is the undershot water wheel provided with buckets near the circumference. Fig. 1 represents a wheel of this kind much used in Bavaria on the river Regnitz, a branch of the Main, where the writer counted no less than 20 in a distance of 1¼ to 1½ miles.

These wheels have a diameter of 16 feet and carry upon one or both sides a row of 24 churn-like buckets each lifting out of the stream, and to a height of 12 feet, not less than 3 gallons of water, emptying it into the side trough shown in the figure, from which it is conveyed to the bank through a conduit hewn from a log. The wheel under consideration was making at the time of the writer's visit 4 revolutions each minute, so that the water lifted was not less than 288 gallons per minute, and probably exceeded 300 gallons. Another wheel with a row of buckets on each side was making 3 revolutions and discharging not less than 450 gallons per minute. The first of these wheels was pumping water at a rate sufficient to irrigate, to a depth of 4 inches every 10 days, 38 acres and the second wheel 60 acres.

In other places where the water must be lifted to a greater height one or another form of water wheel is made to operate a pump, or again in still other cases the hydraulic ram is used.

LIFTING WATER BY WIND POWER.

At the present time there is much talk about the utilization of wind power for irrigation purposes, and where the areas to be irrigated are small, and particularly where the lift is very low, the windmill makes a cheap and effective motor for lifting water, but a single mill never can be depended upon to do work on a large scale.

As the windmill is at present used upon a piston pump, it will be helpful to consider what work can be done by piston pumps under different conditions, and in the table below is given the number of days required to pump the amount of water needed to irrigate 1 acre to the extent of 2 inches and 4 inches, respectively, with a single-acting piston pump working 8 hours per day and making 30 strokes per minute:

Number of days required to pump 2 and 4 acre-inches of water with a single-acting piston pump working 8 hours per day and making 30 strokes per minute.

Diameter of piston.	Time required to pump 2 acre-inches with—		Time required to pump 4 acre-inches with—	
	6-inch stroke.	12-inch stroke.	6-inch stroke.	12-inch stroke.
Inches.	*Days.*	*Days.*	*Days.*	*Days.*
3	20.5	10.3	41.1	20.5
4	11.6	5.8	23.1	11.6
5	7.4	3.7	14.8	7.4
6	5.1	2.6	10.3	5.1
7	3.8	1.9	7.5	3.8
8	2.9	1.4	5.8	2.9
9	2.3	1.1	4.6	2.3
10	1.8	0.9	3.7	1.9
11	1.5	0.8	3.1	1.5
12	1.3	0.6	2.6	1.3

It is claimed by Wolff that the average length of a day's work for windmills in the United States is 8 hours, and they are not likely to average more than 30 strokes per minute where single-acting pumps are used; and this being true, the table above shows what the range of work done by the windmill may be when used for irrigation if worked upon pumps such as are indicated in the table.

It is generally conceded by the best authorities on the subject that existing data bearing upon the actual work which windmills are able to do when used for irrigation are not sufficient to enable tables to be constructed which will show what wheels of different pattern and sizes may be expected to do when set up in different sections of the United States. But if windmills can be set up which will work single-acting pumps at the rate and under the conditions indicated in the table above, then the areas to which 2 acre-inches and 4 acre-inches of water may be applied every 10 days would be as follows:

Areas irrigated by windmills working single-acting pistons 8 hours per day at the rate of 30 strokes per minute.

Diameter of piston.	2 inches every 10 days.		4 inches every 10 days.	
	6-inch. stroke.	12-inch stroke.	6-inch stroke.	12-inch stroke.
Inches.	*Acres.*	*Acres.*	*Acres.*	*Acres.*
3	0.49	0.97	0.24	0.49
4	0.87	1.73	0.43	0.87
5	1.35	2 70	0.68	1.35
6	1.95	3.89	0.97	1.95
7	2.65	5.30	1.33	2.65
8	3.46	6.92	1.73	3.46
9	4.38	8.76	2.19	4.38
10	5.41	10.82	2.70	5.41
11	6.55	13.09	3.27	6.55
12	7.79	15.58	3.89	7 79

From this table it appears that if windmills can be constructed which will work pumps at the rates here assumed, areas varying from 0.24 acre to 15.58 acres may be irrigated at rates of 2 to 4 inches every 10 days.

Wolff[1] gives a table showing the capacity of first-class windmills for work in irrigation, which is based upon results actually attained in practice, and from this the following table is computed:

Number of acres a first-class windmill will irrigate 2 and 4 inches deep every 10 days when working 8 hours per day and lifting the water 10, 15, and 25 feet, respectively.

Diameter of windmill wheel.	Lift of 10 feet.		Lift of 15 feet.		Lift of 25 feet.	
	2 inches.	4 inches.	2 inches.	4 inches.	2 inches.	4 inches.
Feet.	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*
8.5	1.35	0.67	0.9	0.45	0.55	0.27
10	4.27	2.13	2.85	1.42	1.70	0.85
12	7.66	3.83	5.11	2.55	3.00	1.50
14	9.87	4.93	6.58	3.29	3.99	1.99
16	13.79	6.89	9.19	4.59	5.71	2.85
18	22.09	11.04	14.14	7.07	8.64	4.32
20	27.36	13.68	18.25	9.12	11.04	5.52
25	47.06	23.53	31.38	15.69	18.77	9.38
30	95.46	47.73	64.42	32.21	38.08	19.04

[1] The Windmill as a Prime Mover.

It will be seen that according to this table the largest area which can be irrigated to a depth of 4 inches in every 10 days by a 12-foot wheel, lifting the water 25 feet. is 1.5 acres. It should be said in connection with this table, however, that with the improvements which are being made both in the construction of windmills and of pumps adapted to them it is quite probable that considerably higher efficiency will be attained.

LIFTING WATER WITH ENGINES.

When it comes to lifting water with engines for purposes of irrigation the amounts so raised to considerable heights at a comparatively small cost for fuel become very great.

It is claimed that at the present price of gasoline the gasoline engines now made will produce 1 applied horsepower at a cost of 1 to 1.5 cents per hour for fuel. At the higher figure the water necessary to irrigate 1 acre to a depth of 4 inches could be lifted 20 fee high at a fuel cost of 14 cents, and if the irrigation were repeated s times the total cost per acre for fuel alone would be only 84 cents.

At the Wisconsin Station, with a rated 8-horsepower farm engir water has been drawn from a lake through 110 feet of 6-inch suct pipe to a height of 26 feet at the rate of 22½ acre-inches per day, ' 1 ton of Indiana block coal. At $4 per ton for coal the fuel cos 4 acre inches lifted 26 feet high was 72 cents, which makes six irrigations cost for fuel alone $4.32, or, upon the basis of a 20-foo $3.03. It should be stated regarding this case that the cost inc the waste of fuel incident to frequent stopping and starting firing up in the morning and allowing the engine to cool down a

The pump used in the case just cited was a No. 4 centrifug lifts not greater than 25 feet centrifugal pumps are the best fo tion on account of their simplicity of construction and long lif ness, and small liability of getting out of order.

The different types of rotary pumps are very effective v and in perfect working order, and water can be lifted with th desired height, but they are subject to rapid deterioration, there is much silt in the water. Neither of these types of be advantageously used where they must be placed more th feet above the water supply.

Some form of plunger pump is necessarily resorted to ir the water is more than 20 feet below the surface, and i pumps for irrigation purposes, especially where the dr limited, it is very important that the suction and disch have diameters nearly or quite equal to the diameter itself, otherwise the loss of power through concussio unnecessary velocity of discharge will be great.

WATER FOR IRRIGATION FROM WELLS.

The ordinary farm well as it is generally constructed can not be depended upon to supply water for the irrigation even of kitchen gardens of any considerable size. It is possible, however, so to construct farm wells that they will yield much larger supplies of water than they ordinarily do. The most common fault with farm wells is that they do not extend deep enough below the lowest seasonal level of standing water in the ground. When a large supply of water from a well is desired at all seasons of the year, the depth of standing water must be great unless the water is derived from a stratum of gravel or coarse sand, and usually the deeper the water is in the well the more water can be drawn from it, other conditions being similar. Where water is obtained in sandstone in which the wells are drilled, the larger the diameter of the well and the deeper the water in the well the more water it will supply. But where the sandstone is much fissured, so that the water can percolate into fissures and flow along the fissures to the well, the supply of water from it is very much increased.

There is at Babcock, Wis., a 6-inch well 74 feet deep, the last 35 feet of which is in sandstone from which the water is derived, and the natural depth of the water in the well is about 68 feet. This well yields daily 76,800 gallons, which is enough to irrigate, if pumped to full capacity 10 hours per day, 5.89 acres 2 inches deep every 10 days, and 2.95 acres 4 inches deep in the same time. Or, pumped continuously, it might be made to irrigate 14.14 acres 2 inches deep or 7.07 acres 4 inches deep every 10 days.

These figures serve to show the maximum areas which can be irrigated from wells except in those sections which are underlaid by artesian waters under sufficient pressure to cause them to rise to or overflow the surface.

A 10-inch well at Madison, Wis., 750 feet deep has a tested capacity of 599,040 gallons every 24 hours. If this were pumped continuously it would be sufficient to irrigate 110 acres 2 inches deep every 10 days, and 55 acres 4 inches deep. Or, if the well worked 10 hours per day the areas irrigated would be 46 acres 2 inches and 23 acres 4 inches deep.

As an extreme example of the amount of water which may be supplied by a single artesian well that of Chamberlin, S. Dak., may be cited. This well yields 5,000 gallons per minute at a temperature of 71.6° F., or enough to irrigate 657 acres of land to a depth of 4 inches once in 10 days throughout the year.

THE CONSTRUCTION OF RESERVOIRS.

Reservoirs are necessary where pumps are used for purposes of irrigation, particularly if windmills are used. The location of the reservoir should be such that its level is above that of the land to which it is to

supply water. The deeper the reservoir can be made the less will be the loss by evaporation and usually also by leakage, but if the water supplied to it is too cold to use it will warm faster in a shallow reservoir.

Where the soil is of a clayey nature a very good reservoir may be made by first plowing and removing the sod to a distance beyond the border of the proposed walls, because if introduced into the wall it will leak. The earth is then plowed and scraped into a broad ridge having the inside slanting in order that the waves shall not erode the embankment. While the earth is being deposited in the wall it should be trampled firm and close. When the proper height and form has been given to the walls of the reservoir it is necessary to plow and thoroughly pulverize the bottom to a depth of 5 inches preparatory to puddling it. If the reservoir is circular in outline the loosened soil should be first wet at the center and thoroughly puddled there by trampling with a team. Then by widening the wet area the team may be driven round and round until the sides are reached and the whole thoroughly

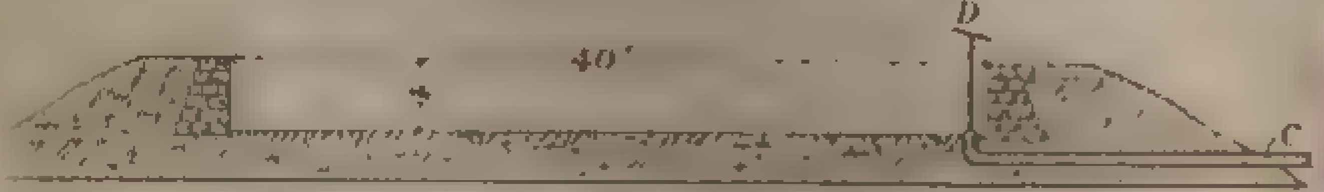

Fig. 2. Construction of reservoirs.

worked into a mortar. In this condition, if thoroughly puddled, reservoir is nearly water tight. To prevent washing the inner may be covered with a layer of coarse gravel or crushed rock.

If a perfectly water tight reservoir is desired the bottom shoul cemented, coated with asphalt and sand, or 6 or 8 inches of brick used in the puddling.

The reservoir at the Wisconsin Station is cemented on the un earth bottom and on the sides, which are of stone and vertical the cement had become dry the surface was painted with (boiled until thick) when cold, and applied with a broom fr In this condition it is water tight.

To remove the water from the reservoir the best plan is t weld steam pipe provided with an elbow and laid with th the elbow level with the bottom of the reservoir and facing closed with a plug to which a long T handle is attached. sents a cross section of reservoir with plug inserted in pipe. The end of the pipe where the plug is inserted sh oughly embedded in a large mass of cement heavy eno

it from being shaken when the plug is taken out or inserted. A reservoir with sloping sides should have the outlet at the junction of the side and bottom, and it will be necessary to build a pier out to it in order to reach the plug.

A reservoir 4 feet deep and 40 feet in diameter will hold water enough to irrigate 0.35 acre 4 inches deep and 0.69 acre 2 inches deep, and 100 feet in diameter will irrigate 4.32 and 2.16 acres 2 and 4 inches deep, respectively.

METHODS OF APPLYING IRRIGATION WATER.

The methods of applying water are so various that only a lengthened discussion can convey a clear idea of them, but it is believed that the following brief suggestions, condensed from a recent article by Prof. L. R. Taft,[1] will be helpful to those desiring a general knowledge of methods of applying irrigation water to gardens and orchards.—[ED.]

The method by which water will be carried upon the land will depend largely upon the surroundings. If there is a large amount of water and an easy grade can be secured, it may be carried in open ditches, which can be easily excavated with a plow and scraper. Where the distance is not great, or if the pressure is considerable, particularly if the water is pumped, riveted sheet-iron tubing or steel gas pipe can be used. These are readily put together and taken apart as desired, and gates and water plugs may be attached at will. If arrangements are made to drain the pipes, or if they are taken up in winter, they may be placed upon or near the surface.

The size of the pipes needed will depend upon circumstances. For tracts of from 5 to 10 acres a sewer pipe 4 inches in diameter is desirable, although a 3-inch pipe would answer if there is a fair fall. When using iron pipe the size of the distributing pipes upon tracts of a half acre or over should be 2 or, better, 2½ inches. For the main supply pipe from the pump or reservoir a somewhat larger size will lessen the friction and increase the capacity of the system, but if the distance is considerable it will cause a large outlay, and it might be cheaper in the end to use a smaller size and take a little more time. Wooden or sheet-iron flumes may also be used for carrying the water.

The supply pipe or ditch should take the water to the highest point of the tract to be irrigated, and, if the land is uneven, with several knolls, a branch pipe should be carried to each of them. If there is one point from which the water will flow over all others, it can be distributed from that point in flumes or ditches to the furrows and thus spread over the land. While this will lessen the expense if pipes are used, it will be better not to attempt to water more than 1 or 2 acres from a single hydrant. If applied from a hose, it is not desirable to have the hydrants more than 200 feet apart, requiring a hose 100 feet long. For a tract not over 200 feet wide and from 300 to 500 feet long, measuring down the slope, a single hydrant at the middle of the upper side will be sufficient. A regular hydrant can be constructed if desired, but if there is a T with a gate valve at the point where the hose is to be attached it will answer every purpose.

One of the best methods of distributing the water from the hydrants is by the use of wooden troughs. They may be put up permanently along the head of the rows or may be made portable in sections of 16 feet. They should be from 6 to 8 inches square inside or 8 inches deep if triangular. Along one side, at intervals of from 3 to 20 feet, according to the crop for which they are to be used, there should be holes from 1½ to 2 inches in diameter, closed by zinc or galvanized sheet-iron gates. If

[1] U. S. Dept. Agr. Yearbook 1895, p. 233.

the land slopes much, there should be an occasional drop in them. To control the flow of the water, wooden sliding gates are desirable at frequent intervals and at the end of each section of trough. By means of the small gates the water can be distributed to a number of rows at a time and the flow can be regulated at will.

If neither troughs nor pipes are used, an open ditch can be run along the head row, and this will serve the same purpose. If ditches are used, it is desirable that small wooden boxes, closed at one end with a sliding gate, be placed at points where the water is to be drawn out, but the water is often applied by making openings in the bank through which it can be drawn.

Having the water upon the land, it can be applied in various ways. Flooding or allowing the water to spread over the surface to the depth of from 2 to 10 inches was formerly extensively used, but it is now employed only for grain and similar crops. The most common method for vegetables and fruits is to make furrows and run the water along in them, so that it can soak into the soil. If properly arranged, the water can not spread upon the surface, and, by turning back the furrows as soon as the water has soaked in and cultivating the soil, the moisture can be prevented from evaporating (fig. 3).

FIG. 3. Furrow method of irrigation.

Care should be taken to so lay out the rows in the orchard or garden that the furrows for the water can be run at a very slight slope, 2 or 3 inches in 100 feet being all that is desirable, while 1 foot in 100 feet is an extreme slope. With a little care in laying out the furrows water can be used upon land that at first sight it will seem impossible to irrigate.

Subirrigation is the term applied to the running of water through pipes laid below the surface of the ground and allowing it to soak out through cracks or holes made for the purpose. The pipes are generally common drain tiles, from 2½ to 4 inches in diameter, laid at depths of from a few inches to 2 or 3 feet. Particularly upon muck or swampy land if they are placed at a considerable depth, they will do good service as drains, besides distributing water in dry season. By having the ends of the lines of tile open into a ditch, the water can be carried off when there is a surplus, while, by damming the ditch and filling it with water, the tiles will carry it back for several hundred feet and moisten a space upon either side of from 15 to 40 feet.

They should be placed 12 inches deep in garden loam soil at a distance of 12 or 15 feet apart, but in very light sand or stiff clay shorter intervals will be advisable. The tiles should have a very slight slope, for if there is much head the water will break out unless they are laid at a considerable depth. Several lines may be joined to a larger line laid across their ends, although if each line of tile is supplied independently, a more even distribution will be obtained.

Upon a small garden where the water supply is small, or if it is delivered in small pipes, this method of watering is of value, as the water needs only to be turned on and it will distribute itself without further attention.

While there is a saving of labor in this method, the cost of tiles and the expense of laying them make it much more expensive than furrow irrigation. It has few advantages over furrows for fruits and the ordinary garden crops. As water can be applied in furrows for fruits or large areas of vegetables at from 50 cents to $1.50 per acre, according to the crop and the amount of water available, one can not afford to go to the expense of fitting the land for subirrigation, except where the tiles are needed as drains.

For flower beds and lawns where water can not be applied in furrows tiles can often be used to good advantage. Placed at the depth of 1 foot and as nearly level as possible, they will distribute the water quite evenly over a space from 8 to 16 feet in width. For short lengths the flow of the water should be restricted to the amount that can be given off by the tiles.

For garden crops grown in rows more than 2 feet apart, the water can be run in furrows made a few inches from each row while the plants are small, and halfway between them when they have filled the ground with their roots. For narrower rows, down to 16 inches, it will answer if furrows are made in every second row, while for crops grown in very close drills irrigation may be provided for by leaving a slightly wider space every fourth row in which to run the water. When the crops are sown broadcast, the water may be applied by making furrows from 4 to 10 or even more feet apart, and it will be of far more value than when spread upon the surface.

The condition of the plants is the best indication of the necessity for applying water. If in a time of drought the leaves wilt or curl, or take on an unnatural, dark color, water can generally be used to advantage. Although one or more waterings are occasionally necessary while the plants are small, potatoes, tomatoes, peas, and similar crops are more likely to suffer from lack of water after the fruits and tubers form, and it should then be used in liberal quantities. For all such crops it is seldom desirable to irrigate while the plants are in blossom, as it tends to start a new growth and prevent setting. After the crop has set, particularly in case of the potato, no check to the growth should be allowed from lack of water, as when it is applied a new growth will start, a second crop will set, and the result will be a large number of small potatoes.

More than 800 to 1,500 barrels per acre should not be applied at one time, as, if heavy rains follow, the ground may be saturated. Even with the most thorough cultivation, anywhere from a half inch to 2 inches of water per week can be used to advantage by vegetables during May, June, July, and August, and unless the natural supply available approximates that amount it should be supplied artificially in proportion to the character of the soil and season and the needs of the crop, 1 inch being taken as an average for each application for good garden soils. Care should be taken to prevent the flowing of the water over the surface, and particularly from coming in contact with the stems and leaves of the plants. After each watering and after every rain the ground should have a shallow cultivation, and this should be repeated at least once a week.

For orchards as well as for other crops it is better to use a number of small streams rather than one or two strong ones, as there will be less washing of the soil, and a more even distribution of the water can be secured. A flume or head ditch will aid very much in securing this.

In locating the rows such an arrangement should be made as will secure a proper slope for the furrows, which should be from 1 to 6 inches in 100 feet. While the trees are small a furrow upon either side of each row will answer, but as the roots spread additional furrows 3 or 4 feet apart should be made, until finally the entire space is irrigated (fig. 4). Too much water and too frequent applications are more likely to be harmful than too little water, and ordinarily there will be no necessity for watering until the fruit is half grown, and from one to three applications, the last one not later than the middle of August, in order to allow the growth to ripen, will usually suffice. The use of water during a week or two before and continuing until two weeks after blossoming is not desirable.

Great injury is often done by the drying out of the trees in winter, and if the autumn is very dry it will be well to irrigate the trees just before the ground freezes. The amount of water required by orchards is from 1 to 2 inches at each application, while the frequency of watering must depend upon conditions. When a loam soil

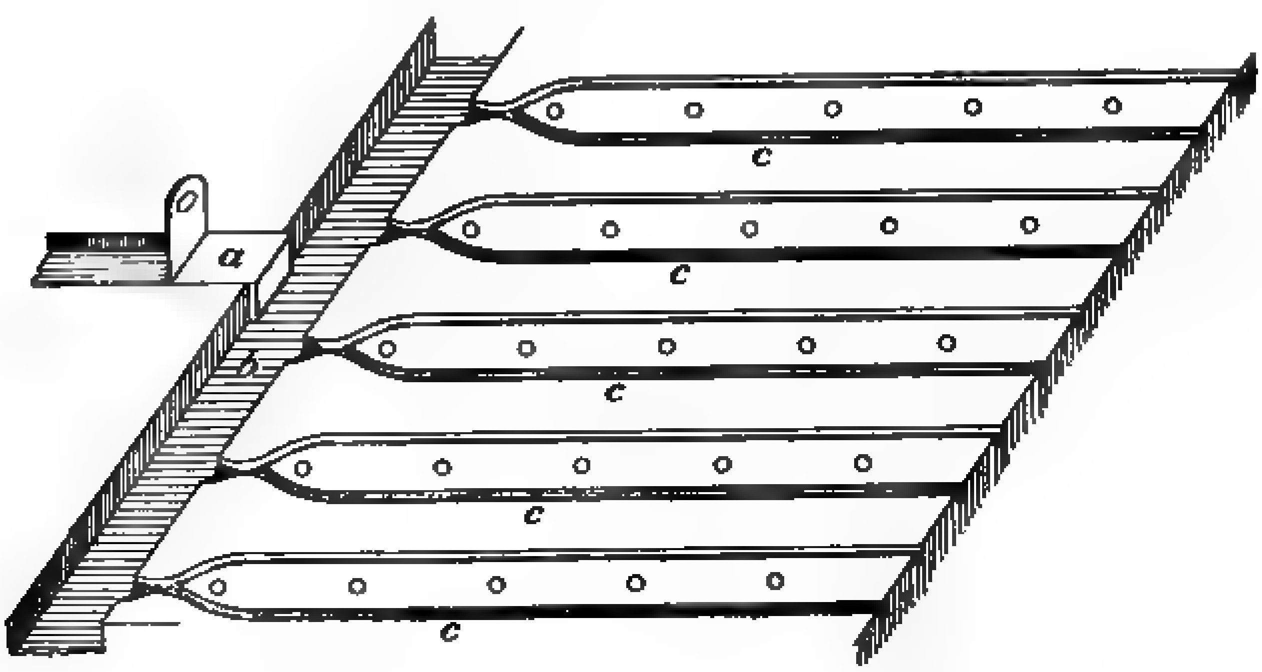

FIG 4.—Irrigating young orchard with furrows: *a*, sluice; *b*, head ditch; *c*, furrows.

taken from a depth of 5 or 6 inches will not pack in the hand it is an indication that water is needed. Ordinarily once in from two to three weeks is as often as water need be applied.

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U. S. DEPARTMENT OF AGRICULTURE.

FARMERS' BULLETIN No. 116.

IRRIGATION IN FRUIT GROWING.

BY

E. J. WICKSON, M. A.,

Professor of Agricultural Practice, University of California, and Horticulturist of the California Experiment Station.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., February 15, 1900.

SIR: I have the honor to transmit herewith a paper on irrigation in fruit growing, by E. J. Wickson, M. A., professor of agricultural practice in the University of California and horticulturist of the California Agricultural Experiment Station, prepared under the supervision of Prof. Elwood Mead, irrigation expert in charge of the irrigation investigations of this Office, and to recommend its publication as a Farmers' Bulletin of the Department.

Respectfully,

A. C. TRUE,
Director.

Hon. JAMES WILSON,
Secretary of Agriculture.

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IRRIGATION IN FRUIT GROWING.

INTRODUCTION.

Throughout a considerable area of the United States irrigation is indispensable to the growth of fruit. Throughout a greater area irrigation is essential to the growth of fruit of the highest quality and market value. Throughout a still greater area the availability of irrigation is a surety against occasional losses of crops and injury to trees and vines through drought. There are no data for accurate definition of these particular areas, but it is a fact, never so generally appreciated as at the present time, that the fruit grower in all except a few of the most humid regions of the country may look upon a water supply, available for use when desirable, as an element of great value and an assurance of safety in his business enterprise. Evidently the so-called "arid West" is no longer to stand alone in proclaiming the advantage of irrigation. Wherever fruit crops were injured or lost by the long drought of the summer of 1899, there may be found testimony of the benefit which would have accrued if the grower had been ready to regulate his soil moisture by irrigation. For this reason the art of irrigation is becoming far more than a sectional question in this country, and the knowledge of it which has been gained by a half century of experience in one section becomes of direct practical advantage in nearly all sections. The time has come when fruit growers everywhere must understand the elementary facts, at least, of the relation of irrigation to fruit production and of the development, distribution, and use of water in horticultural enterprises.

It should be an inspiring reflection to an American that he need not seek abroad for the best irrigation methods in the growth of fruits. The irrigation pioneers of the far West ransacked the whole Mediterranean region of Europe and Africa and farther India for example and suggestion and found little which American insight and ingenuity could not improve. The result has been that during the last decade commissioners from nearly all governments having possessions suitable for fruit production have made personal examination of American methods and have commended them for superior capacity and efficiency. It is not contended that America has the greatest irrigation enterprises of the world. Such comparison is beyond the scope of this writing. But for irrigation enterprises as applied to the growth of fruit, it is claimed

t there are none so great nor so rationally and effectively method-
d as those of this country. For all these reasons it is thought that
e farmers and fruit growers of the United States may be interested
a general statement, in as compact a form as possible, of the rela-
ons of irrigation to fruit production, and of irrigation methods, as
ey have been demonstrated by Pacific coast experience, to the end
hat recourse to irrigation, wherever it be found desirable, may be
acilitated and promoted.

IRRIGATION WITHOUT CULTIVATION.

A brief historical illustration is instructive, as showing how conceptions of the necessity and desirability of irrigation in fruit growing may change and how ill placed is any prejudice for or against irrigation as such. The Spanish missionaries who entered California from Mexico in 1769 established fruit gardens and vineyards with irrigation facilities at about fifteen points along about four hundred miles of the coast region of the State. They laid off their plantations in old Spanish style and proceeded upon the assumption that fruit could not be grown in California without irrigation. The few adventurers, sailors, and trappers who came to the State from all countries during the first half of this century accepted the missionary view of the case, and most of them, having neither energy nor ambition to develop and distribute water, lived upon beef and beans with such occasional indulgences in wine and fruits as they could get from the missions. There were a few who emulated the example of the padres, but were content to accept their methods of frequently running water through permanent ditches to the uncultivated orchard or vineyard. This was the first conception of irrigation as essential to the growth of fruits in a country with a rainless summer.

CULTIVATION WITHOUT IRRIGATION.

Soon after the gold discovery and the arrival of Americans in multi
tude, it was seen that tillage of the surface soil prevented evaporatio
to such an extent that fruit trees and vines could make great grow
and bear heavily with such moisture as was conserved in the soil fr
the rainfall of the wet season. It was a great surprise that trees coul
this even though no rain fell for several months, and a sharp rea
from the old Spanish conception of constant irrigation resulted. '
then claimed that irrigation was unnecessary and that thorough s
cultivation during the dry season would produce better fruit
irrigation. This was the second conception, viz, that irrigati
not only not essential, but was an injury to fruit even in a coun'
a rainless summer, and that regions which would produce fruit
irrigation enjoyed a very superior natural endowment wh
hardly be overestimated. For many years the conflict be
advocates of irrigation and nonirrigation continued. Mean'

ence was teaching valuable lessons. It was found that in some soils and situations the nonirrigation policy failed to secure satisfactory crops of good fruit and that a properly regulated irrigation practice succeeded in doing it. It has required nearly a quarter of a century of trial and discussion to arrive at the true, rational, and practical demonstration of the matter, which is that an ample moisture supply, available all through the growing season, is necessary to the best work of the fruit tree or vine, without regard to whether that moisture comes from rainfall or irrigation; that irrigation or nonirrigation may be either right or wrong according to the conditions of soil or season or rainfall or the kind of tree. They may be both right and wrong in the same locality in the same month. The long process of inquiry, experiment, and observation by which this conclusion was reached involves propositions of universal applicability, the demonstration of which is of importance to operators in both arid and humid regions and affords a motive for the present discussion.

IRRIGATION AND CULTIVATION, AND THEIR MUTUAL RELATIONS.

The issue between irrigation and cultivation arose at the very beginning of systematic fruit growing in California, as has just been suggested. No adequate understanding of the tillage principles involved was then exhibited; the empirical discovery of the facts was a surprise; the quick and wide use of the facts constitutes one of many striking illustrations of the versatility of the American mind in dealing with the strange phenomena of an arid region, which has marked the advancement of California agriculture. The experience of California fruit growers in the matter of tillage as related to moisture conservation and to stimulation of plant growth affords unique and emphatic illustration of the principles laid down by our best writers on these subjects. As these writings are readily accessible, attention will be paid rather to the effectiveness of proper cultural methods, as learned by experience, which are widely applicable, even beyond the arid region in which they have secured adoption.

Common observation showed at the beginning that fruit trees and vines, if well planted during their dormancy in the wet season, would make a fine growth in the spring and continue it during the early part of the dry season, but would suffer, and in some cases actually perish as the dry season advanced, because the soil would become so dry to a depth of several feet that the root hairs would die and continued evaporation from the leaf surface would extract every particle of moisture from branch and root and destroy the young tree. If the soil were heavy, it became as hard as a rock, so that a post hole could be dug only with a crowbar; if it were light, it would lose all adhesiveness and become either ashy or sandy. In both cases the soil would become not only dry, but hot, and incapable of maintaining plant growth. On the other hand, in places only a short distance away, on the same

soils, where the surface had been mellowed after the late rains had compacted the surface, directly opposite behavior of the plants was seen; growth was continued in good form and color, fruit was carried to astonishing size, and the trees and vines were thrifty and vigorous during months of cloudless skies, hot sunshine, and dry air. The suggestion of such a contrast was speedily made use of, and the discovery that better fruit could be grown by surface tillage than by the old Spanish practice of frequently running water over the hard surface was hailed with enthusiasm.

CULTIVATION AS A RELIEF FROM IRRIGATION.

From this early announcement of the efficacy of tillage of orchard and vineyard the resort to plow and cultivator became general, and nearly half a century of experience justifies the conclusion that adequate cultivation obviates the necessity of irrigation, providing (1) there is sufficient rainfall or underflow at any season to support a year's growth and fruitage; (2) there is sufficient retentiveness in the soil to hold water from evaporation or leaching; (3) there is sufficient depth of soil to constitute a reservoir of adequate capacity. Soil and moisture conditions are of universal occurrence, and are therefore worthy of consideration wherever fruits are grown, and the understanding of them may be very helpful to those who are beginning in new regions, and in many cases suggestive of new methods and policies in older regions. It is important that we define them.

Adequate cultivation.—This has reference both to water reception and water conservation. Wherever the rainfall is liable to come in heavy downpours there is great danger of loss by what has been called the "run off." This will vary according to the nature of the soil and the local topography, but even under the most favorable conditions it is a great loss unless the rains are very gentle and occur at intervals. When the soil is hard and compacted at the surface it acts as a roof and sheds almost all of the water into the drainage channels. The writer has seen instances in which rainfall enough to send moisture to a depth of several feet has penetrated only a few inches. Adequate cultivation begins, then, with the opening of the surface for water reception, and unless this is done the game is stopped at its beginning. The subsoil reservoir will never be filled unless the cover is porous by nature or rendered so by coarse tillage at the beginning of the rainy season.

Adequate cultivation for water retention means such treatment o the surface after the rains have fallen as will reduce evaporation to minimum. A compact surface layer is not only slow to receive wat from above; it is also quick to lose it by surface evaporation as it ri progressively from below. The result of this loss is the deep dr which is destructive first to root hairs and finally to the whole p A loose surface layer prevents this escape of the moisture into th and increases in effectiveness as the soil is more and more finely pu

ized and as the loose layer becomes deeper. Cultivation, then, to retain moisture for the use of the roots of trees and vines during the dry season consists in maintaining a deeply pulverized surface. To secure such a surface pulverizing once is not enough; even though no rain may fall, the surface will become recompacted and must be repulverized. In a soil thus treated moisture is always present quite near the surface, and so great is the contrast between this and the deep dryness of an uncultivated soil that the impression currently prevailed that cultivation produced moisture. It does not produce it; it merely prevents its loss by surface evaporation.

Adequate moisture.—Evidently this condition is fulfilled when the natural moisture thus faithfully conserved is enough for the season's needs of the tree or vine. This moisture may come from rainfall on the particular area or from rainfall supplemented by underflow from adjacent catchment areas. How can it be told when there is enough? The experience of the arid region is that this can not be answered by measurement of rainfall. There are many places where an annual rainfall of less than 20 inches is adequate for the full growth and fruitage of the tree; there are other places where twice and even thrice that amount will not obviate the necessity of summer irrigation. The test of the matter is the behavior of the tree during its full cycle of growth and fruitage.

Retentive soil.—Another condition which will render adequate cultivation effective or not is the mechanical character of the soil. The soil must contain enough fine particles to make it hold water well. Excessive fineness makes adequate cultivation difficult; excessive coarseness makes cultivation ineffective; that is, the soil will dry out in spite of it, both by evaporation and drainage. The ideal fruit soil is a loam, because it is coarse enough to be cultivated readily and fine enough to prevent the too free access of air and to prevent the too rapid descent of water by gravity. This favorable condition between coarseness and fineness is prevalent among the predominating light loams of the arid region, in the alluvial soils of the river banks, ancient and recent, and in many of the upland soils resulting from the decomposition of the country rocks. It is the highest type of soil for almost every cultural purpose, and it meets its highest use, perhaps, in the growth of horticultural products, because they command highest values.

Deep soil.—The third condition essential to the highest effectiveness of adequate cultivation in the production of fruits is a deep soil. This is the direction in which the soils of the arid regions are uniquely eminent and the full significance of soil depth is only now coming to be recognized. Rich, deep soils have been prescribed for fruits from time immemorial, but formerly this conception proceeded chiefly upon the vast amount of plant food thus rendered available. Depth as a condition of water holding is not less important. In fact, in proceeding by cultivation to escape irrigation, water holding is the ruling function,

because any amount of plant food is useless without adequate moisture to render it available. It is proper to think of a deep soil as a great subterranean reservoir as well as a great storehouse of plant food. Into this reservoir the water sinks through the surface, roughly broken at the beginning of the wet season, passing to the lower strata so readily that large downpours are quickly absorbed and a large volume of water is thus taken below for the use of the trees during the following summer. The surface, by the coarseness of the soil particles, is kept from puddling, and can be replowed or cultivated during the wet season if desirable to prevent too rank a growth of weeds, or to turn under a green manure crop. In such a deep soil trees and vines root deeply, a penetration of 20 to 30 feet in soils free and fertile to that depth having been repeatedly noticed in well digging. With such an available water supply perfect cultivation to prevent loss by surface evaporation will enable trees and vines to proceed through a growing and fruiting season covering half the year without a drop of rain, always manifesting the fullest thrift and vigor. In fact, in some parts of the Pacific coast where the winter rainfall is unusually heavy and fall frosts sharpest cultivation has to be stopped late in the summer to allow a certain amount of drying of the soil to induce the tree to stop its extension and mature its wood seasonably. On the other hand, in other parts of the coast with less rainfall and with less danger of frosts the cultivation cover of the soil reservoir is maintained until the opening of the succeeding rainy season to support late growth and to carry over a part of the conserved moisture to protect the trees in case the following year's rainfall should be scant. In this deep-soil storage of water lies the secret of the drought endurance of trees in the arid region. They are prepared for drought by deep rooting in a protected reservoir of moisture. The contrast is seen in the behavior of trees on uncultivated shallow soils in the humid regions of this country and Europe, where a few weeks of drought destroys vast values in fruit crops and cripples the trees for following years. There are instances in abundance also in the arid region where the soils are not deep enough to form such a reservoir as has been described. For these reasons cultivation can not always guarantee the thrift and success of the tree, but unquestionably in orchards which have been kept as pasture fields, or where very slack cultivation has been practiced, there are many instances of deep soils which have not been able to discharge their proper function in supporting the summer thrift and fruiting o' trees because their reservoir cover has never been opened to receiv the full rainfall, and is never closed to retain such part of it as th did receive. In many places, therefore, cultivation may complet remove the necessity of irrigation.

WHEN IS IRRIGATION DESIRABLE?

Obviously, when the best work for moisture reception and retention is done by the fruit grower and still the tree shows distress during drought and becomes irregular in bearing in regions to which it is well suited, or when the fruit is not of satisfactory size and quality even when the trees are properly pruned and thinned, it is usually desirable to secure irrigation to supplement the natural moisture supply. This assumes that the study of the behavior of the tree is the best guide to an understanding of its needs. This is plainly the conclusion to be drawn from long experience in Western irrigated regions. While it is perfectly true that there is a direct relation between the normal rainfall and the need of irrigation, and the general prevalence of irrigation may, to a certain extent, be mapped upon the curves of least rainfall, it is also true that large rainfalls do not necessarily free a locality from the necessity of irrigation. This fact has been foreshadowed in the discussion of cultivation. If it should appear that a normal rainfall of 15 inches is enough to assure the profitableness of deciduous fruits in some valleys, it would not be safe to assume that 40 or even 50 inches would preclude the necessity of irrigation in others. As a matter of fact, a rainfall of 40 inches might destroy many fruit trees on a level stretch of heavy soil by long submergence of their roots in some places, while 40 inches in another place, poured upon a shallow, unretentive soil, might not bring an early peach to perfection. It is therefore unsafe to write an irrigation prescription upon a rainfall record. Reasonable accuracy could be secured by a formula which includes rainfall, soil, slope, depth, and character, summer temperature, and atmospheric humidity, and the age and character of the tree; but this would involve wearisome computations. Moreover, all theoretical forecasts based upon computed moisture requirements and local rainfall are apt to include wide errors. The study of the tree and its fruit is most satisfactory, to the practical fruit grower at least.

From wide observations in many regions for many years it is possible to mention the following as fundamental facts:

(1) There are wide differences in the moisture requirements, not only of the different kinds of fruit trees, but of the early and late varieties of the same fruit.

(2) Trees of the citrus family require much more water than those which drop their leaves during a part of the year.

(3) But all evergreen fruit trees do not require more water than all deciduous fruit trees; for example, the olive will bear well with less water than is required by a peach; still, satisfactory olives must not be expected unless the tree has what it needs for free growth.

(4) The needs of all trees are conditioned upon their age and work. A moisture supply which may bring satisfactory growth to young trees may not enable the same trees to bear regularly and profitably.

Shallow-rooting fruit plants, even if well cultivated, may perish ıg a drought which will have no evil effect upon fruit trees and s on the same soil, because of the deep rooting of the latter. vidently, then, conclusions as to the desirability of irrigation must drawn with due knowledge of the general requirements of the ›wth contemplated, as well as character of the land to be planted; t there are specific needs of the tree pertaining to its different ases of growth and fruiting which are also involved in the question when irrigation is desirable. Long observation of these phenomena ı a region where there has been extended practice both with and ·ithout irrigation may yield some facts, widely significant, of moisture equirement, as learned by practice, to compare with the conclusions :eached by systematic experimentation.

EFFECTS OF INSUFFICIENT MOISTURE.

POOR GROWTH.

This could be passed as an obvious suggestion were it not that so many fail to recognize in a lack of moisture the cause of evil manifestations which they try to explain otherwise. Tree tonics and fertilizers, fungicides, sometimes even insecticides, are applied to trees which are simply famishing for water. Even young trees will show too light a color, or the outer edge of the leaf will die, or the young shoots will die back, not for lack of plant food nor through the action of any blight or disease, but because the root hairs have dried off. This has already been mentioned as a result of lack of cultivation. It also occurs with the best of cultivation when there is no moisture to be conserved by it. Die back may result from any injury to the root hairs; it may be caused by excess of water in the soil as well as the lack of it. Whenever the appearance comes to leaf or shoot, the moisture condition of the soil should be first learned by deep digging, and when the spad strikes the hard, dry layer or when it throws out dust a good soaki of the soil should be given. In many cases the surface may be mell and moist and the subsoil dry.

Experienced growers soon come to recognize the signs of distress i famishing tree. Small leaves and short and thin wood growth are p indications. But there may be enough moisture early in the seas enable the tree to escape these. In midsummer the leaves ma their normal aspect and be slightly curved, limp, and, as it we less. Fading and wilting will ensue unless moisture be s Water should be given before these signs of acute distress

POOR FRUIT.

The bearing tree, as stated, may fail where a young tr only wood growth may do well. There may be ample moi in the summer so that a good crop of fruit may set and w

formed, but moisture may be scant later when the tree needs it in generous amount to fill out the fruit and give it proper flavor and aroma. Even though the burden of the tree be reduced by proper pruning and thinning, it may still, for lack of moisture, bear only small, tough, and ill flavored fruit. The preventive for this is irrigation applied in advance of the need. Such a check to growth can not be wholly cured.

INTERMITTENT BEARING.

Lack of moisture may prevent bearing the following year. The full annual duty of the tree is to perfect its fruit and to prepare for the next year's crop. A continuous moisture supply is necessary to maintain activity in the tree until this is accomplished. The tree will make a large draft upon soil moisture while making new wood and large fruit, and if moisture fails then it may be forced into dormancy before it can finish good strong fruit buds for the following bloom. If the distress be great the bloom may be scant or even fail to appear at all; if it be less there may be full bloom, but too weak to set the fruit well and no crop will be borne. Relieved of its fruiting, the tree will make new wood and fruit buds for the following year. Thus the tree, owing to partial moisture supply, forms the habit of bearing in alternate years. Though this habit may also result from other conditions as well, it is a fact amply demonstrated by experience in the arid region that insufficient moisture supply, even in rich soils and with the best care of the tree, will cause this undesirable alternation of bearing and nonbearing, and that however good other conditions may be, regular and satisfactory bearing can be assured only by the presence of adequate moisture.

Any of the foregoing appearances and behaviors of the tree are indications of the desirability of irrigation at some time and in some amount, and to secure the best results from fruit growing they should all be anticipated and prevented. Evidently they do not all pertain alone to what are known as irrigated regions, but they are at times encountered by growers everywhere. At present we have no adequate idea of how much is lost, even in the regions of summer rains, by irregular and intermittent moisture supply of fruit-bearing trees and vines. Great as these losses undoubtedly are they are capable of prevention along the lines of practice which have been learned by experience in the arid regions.

WHEN SHALL WATER BE APPLIED?

Evidently water should be applied in advance of any suffering by the tree. It is a mistake to allow the tree to fall into distress and then seek suddenly to relieve it. One advantage of irrigation is that it may save the tree from unseasonable efforts which result in irregular growth, untimely blooming, etc., as has been previously mentioned. It is usually too late to apply water to the best advantage after the tree shows the need of it; its needs should be anticipated.

WINTER IRRIGATION.

In the warmer parts of the arid region, where there is proper character and sufficient depth of soil to constitute the great subsoil reservoir previously described, it is possible to insure the deciduous tree all the moisture it needs for months by free winter irrigation which fills this reservoir just as a heavy winter rainfall could do it. There has been abundant evidence ever since the beginning of irrigation by Americans in California that such irrigation, followed by good summer cultivation, will be effective if the soil is retentive enough. Recent experiment in Arizona has approved for that region the teachings of experience in California. While the deciduous tree is dormant large amounts of water can be safely applied on all, except, perhaps, heavy clay soils, and water may be used at a temperature which would certainly be too cold to use while the tree is in active growth. For winter irrigation free application at intervals sufficiently long to allow deep penetration of the moisture is necessary.

SUMMER IRRIGATION.

When the use of water shall begin during the growing season depends, of course, upon the character and depth of the soil and the needs of the particular growth. The same considerations already urged to determine whether irrigation is needed at all have a bearing upon this question, because earliness of application is merely a degree of that need. Under some conditions, such as exceptional drought in the arid region, it may be necessary to irrigate to maintain the spring growth, and thereafter at intervals of about a month during the whole summer. Usually, however, there is natural moisture enough to start growth, even in the driest regions, and irrigation is first called for to give proper size and quality to the early ripening varieties, and from that on at intervals for the maintenance of growth, the perfec-

of growth enough to fill out fruit buds for the following year. One irrigation at that time, accompanied by a summer pruning of excessive wood growth, has a tendency to develop fruit spurs, maintain verdure and leaf action, and bring the tree to the close of the season in good condition for the next year's bearing. This application is also about 3 acre-inches of water per acre.

The above are used singly when either one or the other seems to be all that the tree requires. Where the need is apparently greater the two are given. This does not seem to be a deep indulgence in irrigation, and it is not, but it is great from the fact that it holds the secret of profit in the orchard; first, in making fine, marketable fruit; second, in laying the foundation for the same result the following year.

FALL IRRIGATION.

Fall irrigation for deciduous trees is found advisable where the rain resources of the region are very scant, so that there may be too great drying of the tissues of the tree during the long, hot autumn, and where prolonged activity of the tree does not encounter killing frosts. In some such places the too early dormancy of the tree is followed by undesirable fall bloom, which can be prevented by prolonging fall growth until a later dormancy. In regions of greater cold, and especially in the interior valleys of the northerly portions of the arid region, late irrigation must usually be carefully guarded against, because it is very necessary that the tree should become dormant early and fully harden its new wood. For the same reason, summer cultivation must stop sooner toward the North, so that a degree of dryness in the soil shall warn the tree to complete its work for the season and prepare for frosts. On the other hand, at some interior Northern points it is necessary to use late fall irrigation to guard the tree against injury by evaporation in dry winter atmosphere. It has been demonstrated that trees adequately supplied with moisture are less liable to winterkilling. These lessons of experience are akin to others previously cited—that adequate irrigation is of inestimable value and that excessive irrigation is dangerous.

Quite different is the practice with autumn and winter fruiting trees which are by their nature restricted to the semitropical regions. Fruits of the citrus family are the most conspicuous instances. They take almost a year to accomplish what the deciduous trees do in a few months. The high summer heat which ripens Northern fruits brings vigorous growth and development to the citrus fruit, but the wonderful chemistry of the ripening processes is restrained. It is reserved for the cooler months of winter. As the tree has no long dormant season, but a number of short naps at intervals, its moisture supply must be continuous and the irrigator must be ever ready to supplement the rains with irrigation as may be necessary all through the autumn months and, on occasion, even into the winter if the rains fail. Size,

quality, and all the characteristics of a perfect fruit, in winter fruits as well as in summer fruits, are all conditioned upon adequate moisture, and the longer the growing season of the fruit, the more water needed, as a rule. Even the olive, which stands at the head for drought resistance, will shrink and shrivel its ripening fruit until its moisture needs are met. The amount of water required and the time of its application depend, then, upon the nature of the growth, as well as upon the nature of the soil which supports it.

FLOWING WATER VERSUS FALLING WATER.

A question which has been mooted for years and discussed with all the force of prejudice and self-interest, as well as of honest doubt, is whether the application of water by the art of irrigation is as good for the plant and the fruit as application by rainfall. The proposition naturally arrayed rainfall districts against irrigated districts, created disputes about land values and over land buyers, between land owners in this and that region. Whether irrigation was an advantage or a misfortune was hotly discussed. The question is now practically settled by demonstration to be found in the experience of thousands, that there is practically no difference between water that flows and water that falls; that there may be too much or too little of either one, and evil will result in either case. Obviously, with irrigation available there is always at first a disposition to use too much water; and to the unwise use of water are due the evils which have been charged against irrigation as such. Some of the phases of the matter are worth brief mention:

(1) The claim that nursery trees grown by irrigation were, from that mere fact, inferior was based upon experience in transplanting trees which had been unduly forced by overirrigation. Immense growth from the bud in a single season of an inch and a half in diameter and 10 feet in height tempted buyers who wanted to get as much as possible for their money. The result of setting out such trees created a strong prejudice against irrigated nursery stock. It is now clearly seen that moderate, thrifty growth is the ideal in a young tree, and if the soil does not hold rainfall enough to secure this, water enough to secure it must be applied.

(2) The claim that irrigated fruit is lacking in aroma and flavor was based upon observation of monstrous, insipid fruit which had been forced into such abnormal character by excessive irrigation. Growers who concluded therefrom that irrigated fruit was necessarily inferior denied water to their trees and gathered small, tough, unmarketable fruit, because there was not enough rainfall to enable the trees to perform their proper function. As it is now conceded that the highest quality, including the delicate aromas and flavors, can be secured only by adequate moisture, it matters not how long since it fell from the clouds nor by what route it reaches the roots of the trees.

(3) The claim that irrigated fruit could not endure shipment was based upon the bruising and collapse of fruit which was unduly inflated by overirrigation. The best fruit for shipping is the perfect fruit, and that is secured as just stated. The fact that the greater part of the fresh fruit shipped across the continent from California has been more or less irrigated, according to the needs of different localities, has settled the point beyond further controversy.

(4) The claim that canners objected to irrigated fruit was based upon the early experience with overirrigated fruit, which lacked quality and consistency. At present the canners encourage irrigation and all other arts of growing which bring the product up to the standards they insist upon.

(5) The claim that irrigated fruit is inferior for drying has the same foundation as the preceding claims, and is just as clearly based upon misapprehension. Watery fruit is obviously not fit for drying, but such fruit is the fault of the irrigator, not of irrigation. One of the plainest deductions from experience is that small, tough fruit makes unprofitable dried fruit, and that the best development of the fruit is essential to the best results from drying. Many comparative weighings have shown that the greatest yield in dried form has been secured from trees which have had water enough to produce good, large fruit. Even to bear fruit for drying, then, the tree must have moisture enough to develop size and quality. If lacking moisture, the tree serves its own purpose in developing pit and skin and reduces the pulp, in which lies the grower's profit.

It thus appears that so far as growth and quality for various uses go there is no peculiar virtue in rainfall, and there is every advantage in wise irrigation, which means using water at proper times and in proper amounts and at proper temperatures. The experience of centuries in various countries shows that irrigation water is often superior to rain water in that it carries greater quantities of plant food.[1] Pond and stream waters in humid regions are often rich in nitrates, which are the most costly and stimulating fertilizers. The surface waters of the arid region are also notably rich in potash and other valuable ingredients. No doubt in many instances irrigation water, except that which comes from wells, is worth in manurial content as much as it costs to secure it, leaving its more obvious benefits a net gain to the irrigator.

DEVELOPMENT AND UTILIZATION OF IRRIGATION WATER.

Development and utilization of irrigation water on a large scale involves engineering and financiering which can only be suggested in this connection. They constitute one of the most important economic questions of the day and are deeply involved in the progress and prosperity of the country. Either proprietary or cooperative enterprises

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[1] This is fully described by Professor King in Farmers' Bulletin 46.

covering considerable acreage require the best professional guidance, and losses and disappointment have resulted from neglect to secure it. There are, however, many individual efforts in the development of water sufficient to vastly increase and improve the production of a few acres, which can be profitably undertaken, perhaps, on the basis of brief suggestions drawn from the experience of others.

DIVERSION FROM STREAMS.

The earliest irrigation efforts consisted in turning aside a part of the flow of a stream into a ditch leading to fertile land at no great distance. An obstruction in the stream sufficient to cause this diversion was often of a cheap and temporary character, which might or might not withstand the periodic freshets—it did not much matter whether it did or not. This operation is very simple and well understood, for there is no particular difference between a diversion for irrigation and one for turning the wheel of a sawmill or gristmill, except that the irrigation diversion is usually more easily and cheaply done because the needed head of water is much less. The "millrace" of the Eastern States, as the writer remembers it, would have made quite a respectable irrigation canal and have supplied a large colony of irrigated farms in the arid region. The "open ditch" cut for the drainage of an upland swale on many Eastern farms would carry enough water to irrigate a good large stretch of meadow or fruit land. Anyone who understands enough of leveling to run the line for an open drainage ditch can do the same for an irrigation ditch, and the cost of construction is the same. When there is but slight grade to the land, so that care is necessary to strike a line which will move off the drainage water with as little fall as will promote flow, the problem is exactly the same as to take out water from a point upstream and deliver it so that it will command the greatest possible area for distribution from its outfall. This elementary lesson in irrigation engineering is understood everywhere in the humid region, and yet possibly some who have only heard of irrigation as something practiced on the Great American Desert have looked upon the taking out of an irrigation ditch as a mysterious art. It has become mysterious, it is true, through the maze of water rights and wrongs in the laws, and it becomes wonderful also when one has to consider miles of construction through sand and rock and loss by seepage and evaporation and all that, but these things will probably intrude in a very mild form, if at all, in the class of small irrigation developments which belong to individual efforts in States where water is nearly as free as air. Many an idle brook can render very valuable service on a farm without losing volume enough to be noticed, or if the flow be lessened it can be reenforced by the development of more water along its upper courses.

PUMPING FROM STREAMS AND LAKES.

Where large streams are adjacent to fruit lands and diversion at a sufficiently high level is not practicable, elevation by pump to a proper point for gravity flow or direct application from the discharge pipe of the pump is being largely resorted to. On a small scale current wheels[1] and modifications of the Persian pump are employed.[2] The latter is readily operated by horsepower and is cheaply made at home with available lumber and gearing. These contrivances can be constructed and installed by the ordinary farm mechanic. On the river-bank lands in California very large steam and gasoline pumps are used both for drainage and irrigation at different seasons of the year as either is desirable. Recently capacious pumping plants installed upon barges have been used for custom pumping, delivering water to river-side orchards at a reasonable rate. Hydraulic rams are also used to a limited extent where conditions favor them.

A very interesting way for taking water for irrigation when the river is running high between levees which protect reclaimed land is the use of siphons over the crown of the levees. To cut the levee would be dangerous and flood gates are few, but water can be delivered here and there by the siphons as desired. Made of galvanized iron strong enough to resist the pressure, the air is exhausted by a pump and the water flows over. Some of the siphons are 2 feet in diameter and deliver a large stream, though smaller pipes are generally employed.

DEVELOPMENT OF UNDERFLOW.

Many streams that flow along over beds of gravel only show part of their water to the poet or fisherman who sits upon the bank. There is usually an underflow beyond all expectations. This is notably the case in the arid region, where the country is so largely made up of rock débris in the form of rock powder, sand, and gravel, through which water readily sinks and pursues its seaward course along the deeply buried bed rock. If there be a water-tight obstruction, such as a dam of concrete, placed upon this bed rock and brought up to the bed of the stream the underflow will rise and add its volume to the ordinary surface flow of the stream at that point. In this way in the arid regions large irrigation supplies have been developed in the beds of streams which in the summer consisted of dry sand and bowlders until the new water was brought to light. This has been done hundreds of times and has multiplied irrigation supplies beyond anticipation. This method lies at the foundation of some large irrigation enterprises and of some of the smallest individual affairs as well. Its feasibility depends, of course, upon whether there are water-carrying media below the bed of the stream, and that can be ascertained by digging or boring. If such be found and moving water be discovered, it is likely that the stream bed is a reser-

[1] U. S. Dept. Agr., Farmers' Bul. 46.

[2] Water Supply and Irrig. Papers, U. S. Geol. Survey, Nos. 1 and 14.

voir which needs only a bed-rock dam to deliver its water at the surface. It is a reservoir of most excellent character, because it can not lose water by evaporation nor capacity by deposit, nor can its dam be disturbed by flood or pressure.

The tunnel is another agency for developing underground water at a chosen delivery point. It has been aptly called a horizontal well. It pursues a spring to its base of supplies; it intercepts water which is moving down between impervious strata and brings it out where it will be useful. Many acres on some farms adjacent to the hills are irrigated by the flow from tunnels and the water is secured at a level which admits of its distribution by gravity on the lower lands.

Perhaps the largest aggregate development of irrigation water from underflow in the humid regions may be realized from employing tile drains as feeders for farm irrigation works. At present these drains discharge the water at once into the country drainage and the quick transit of the water to the rivers developes ruinous floods. It would be of inestimable advantage to hold part of this water to render valuable service to production later in the season when drought may come. Though the aggregate may be great as stated, the realization of it will be by means of tens of thousands of small agencies capable of being arranged by the individual farmer. He has his tiles to relieve upland swales and boggy hillsides of their surplus water. He can easily collect this water in a homemade reservoir from which it may be distributed to orchards or small fruit fields on the richer land below. In this way the farmer with no running water on his place may turn his higher land into a catchment reservoir, which will deliver its accumulations gradually, so that they may be easily controlled and rendered available at the time of the greatest need. All this presupposes the existence of farms comprising uplands and meadow, but both need not be in the same ownership. The owner of lower lands can often use his neighbor's higher farm as a catchment area by taking the outflow from his drains. Such recourse may be denied to the plains and prairie farms, but they may have other sources of supply, as will be suggested.

PUMPING FROM WELLS.

Sinking wells into water-bearing strata to secure irrigation supplies is now being resorted to as never before. New and broader conceptions of the relations of subterranean water to irrigation have recently prevailed. This follows because it may be much cheaper to raise water to adjacent towers than to catch it in a remote ravine and pipe it for miles. However this may be, irrigation undertakings have been recently established very largely upon wells and pumps or upon flowing wells, wherever they can be had. In California during the last three years there have been perhaps ten times as many pumping outfits set up for irrigation as had been employed during the whole earlier irrigation development of the State. Large irrigation companies sank

groups of wells and pumped from them into their distributing ditches and flumes when, for lack of rain, their immense reservoirs went dry. Individual irrigators sank wells and bought pumping plants when the ditch water failed, and have now learned the superiority of home supply, to be drawn up just when it can be used to best advantage, and often to be had for much less than the rates of the ditch companies. Large regions which had never secured irrigation systems, and doubted, perhaps, the need of them, were forced by drought to seek water, and having found it below ground in ample quantities they will not fail in the future to use irrigation as a supplement to the rainfall. To illustrate this advance in well irrigation very comprehensive data are found in the following outline of a systematic inquiry:

In Santa Clara Valley, one of the leading fruit regions of central California, there are about 1,500 irrigating plants of all kinds in the valley proper. About 900 of them have been put in during the past three years. Many of them have centrifugal pumps run by steam. These are the larger plants, from where 15 to 40 horsepower, and in some instances more, are used, and the size of the pumps ranges from 4 to 12 inches. Most of the smaller pumps are run by gasoline, though several use crude oil, and many of them are also centrifugal. Some of these are deep-well pumps, and they are very satisfactory in raising water from a greater depth than 100 feet. From 100 to 500 feet they work admirably.

The cost of pumping differs materially with the different kinds of power, sizes of pumps, and depth of wells. Figuring from what may be a safe average of the actual cost of fuel, a No. 4 pump, centrifugal, with gasoline as power, at 70 feet depth, would cost $3 per day. This would result in 600 gallons per minute, 36,000 gallons per hour, or 360,000 gallons per day of ten hours. Such a stream of water is calculated to irrigate about 5 acres per day to a depth of a little more than 2½ inches. But these figures being of the best experiments, a better and safer estimate would probably be 4 acres per day to a depth of about 2 inches.

But, generally speaking, it is safe to say that at a cost of about $3 per acre for the water the orchards of Santa Clara County can, under the present process, be irrigated two or three times at $6 to $9 per acre per year. The average cost of plant is about $1,200.[1]

Santa Clara County is a region of rather deep wells and the cost is correspondingly high, both for the plant and for the water delivered. In many cases the cost per acre will be only a fraction of that given. But even the higher figures are below the cost warranted by the saving of a fruit crop, as the experience of individuals has shown. These figures are, however, used as a standard, because they are a deduction from broad data, and it is unwise to proceed either upon minimum cost or maximum value produced.

Over large areas of the country windmills are used as motors for irrigation pumps, and careful accounts of their efficiency are available.[2] They unquestionably serve an excellent purpose under favorable conditions up to the limits of their capacity, but irrigation for fruit growing, except in the family garden or on small areas of small fruits, is proceeding upon the basis of motors of higher efficiency. Gasoline

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[1] C. M. Wooster, of San José, California.

[2] Water Supply and Irrig. Papers, U. S. Geol. Survey, Nos. 8 and 20.

engines are being used even up to a capacity of 5,000 gallons of water per minute, but the ordinary plants are less than one tenth of that. Crude oil engines are also used, and steam plants using small stationary and portable engines are pressed into service, while electric motors, along long-power circuits from generators at waterfalls or other great sources of power, are being fully employed. Instances of the profitable employment of all these agencies are abundant all through the fruit-growing districts of the arid region.

STORAGE OF WATER FOR IRRIGATION.

As the diversion and development of irrigation water on a large scale can only be undertaken with ample capital and the best professional advice, so the storage of water in large volume is an undertaking which should be approached by the same route. There have been so many disappointments and such great losses from ill-advised and hasty planning and construction that the public should have learned wisdom in this direction. Even some of the smaller reservoirs have proved to be so insecure or leaky or subject to rapid filling that it is clearly seen that the storage reservoir must be first-class in all the branches of its engineering from location to construction. Still, the great storage reservoir is the sole hope of development of vast areas of the public domain, and all the lessons of experience of the last half century's irrigation engineering in California will be helps to make the new work effective.

But while the large reservoir involves these great problems, the small reservoir which will yield value a hundredfold its cost to a farm, or a small group of farms, perhaps, and be a perpetual surety of profitable production, is neither expensive nor difficult to secure. This is fortunate, because the small distributing reservoir is really the key to the satisfactory use of such small sources of water as are chiefly contemplated in this writing. To distribute water satisfactorily, which involves even spreading over a considerable area in a short time, with the best results to the land and the owner, the water must be had with a certain volume, or "head" as it is usually termed in irrigated regions. A little rill from a spring which, if left to its course, might make only a little sedgy strip across a field or a marshy spot in a corner, can be led to a small water-tight reservoir and it will accumulate until it has a volume which can be spread over a considerable area of ground and possibly increase production the first year, because of the irrigation, more than enough to pay the cost of the reservoir which collected it. This is a fact often shown in experience, and yet millions of such springs are allowed not only to waste themselves but destroy much good land unless drainage intervene and the water only be lost. Only people who have learned the value of irrigation can appreciate the value of this waste and the ease with which it can be turned to profit. Saving the pennies is a traditional method of wealth gaining; saving the drops

of water might be a more apt illustration, considering how hard the pennies are to get. This matter is so important and so attainable with little more than the idle time of man and team that it seems worth while to enforce it with a little calculation: A little spring which runs a gallon a minute yields 14,400 gallons in ten days. This is water enough, if kept from leakage and evaporation, to cover half an acre of ground to a depth of 1 inch; and the same volume flowing continuously would be equal to an annual rainfall of 36½ inches for the same area. Thus a trickling stream from a spring becomes a measurable factor in production, and from this minimum flow and acreage one can easily calculate what large flows will amount to, whether they come from spring or windmill or other source. Simply collect the water into a receptacle of known capacity and note the time required to fill it, and calculations as to reservoir capacity needed and area which may be covered in the distribution are easy. Allowance must be made for evaporation from the surface of the water in the reservoir. The approximate evaporation in any region can be obtained from the nearest station of the United States Weather Bureau. Further allowance must be made for loss by seepage, which will vary with the nature of the soil in which the reservoir is constructed, and the manner of construction, which is discussed under the following heading.

An inch over the whole surface irrigated once in ten days, or 3 inches once a month, according to the depth and the receptive character of the soil, will insure against drought and increase production even in a humid climate, while in the arid region it will establish an oasis of fruits and vegetables in succession through the dry season. In the midst of such surroundings the country home becomes attractive and beautiful where otherwise it would be bleak and desolate. The improved home is the unit in the computation of irrigation advantages.

THE SMALL RESERVOIR.

Obviously the small receiving and distributing reservoir should be above the highest point of the land to be irrigated and below the source of the water, except with pumping outfits. It should also be as near as possible to the land to be irrigated, as increased distance would increase both the cost of conveying the water to the land and the loss of water from seepage and evaporation. The first thought in small affairs in hilly regions is to imitate large undertakings and dam the natural channel and back the water in the small ravine whence the stream flows. This is often wise, perhaps, but it is also often difficult to escape loss by seepage and to get sufficient capacity without too high a dam, and there is such great danger of washouts by excess of storm water that a reservoir out of the course of the stream, to which water may be conducted, is better. Excellent suggestions on the construction of the small reservoir, with cross-section drawings, are given in Farmers' Bulletin No. 46. In a coarse soil thorough puddling of bottom and

sides with clay loam, or a mixture of clay with the local soil, will make the reservoir hold water, but a lining of cement or asphaltum will be better where there is not frost enough to break up such materials. In

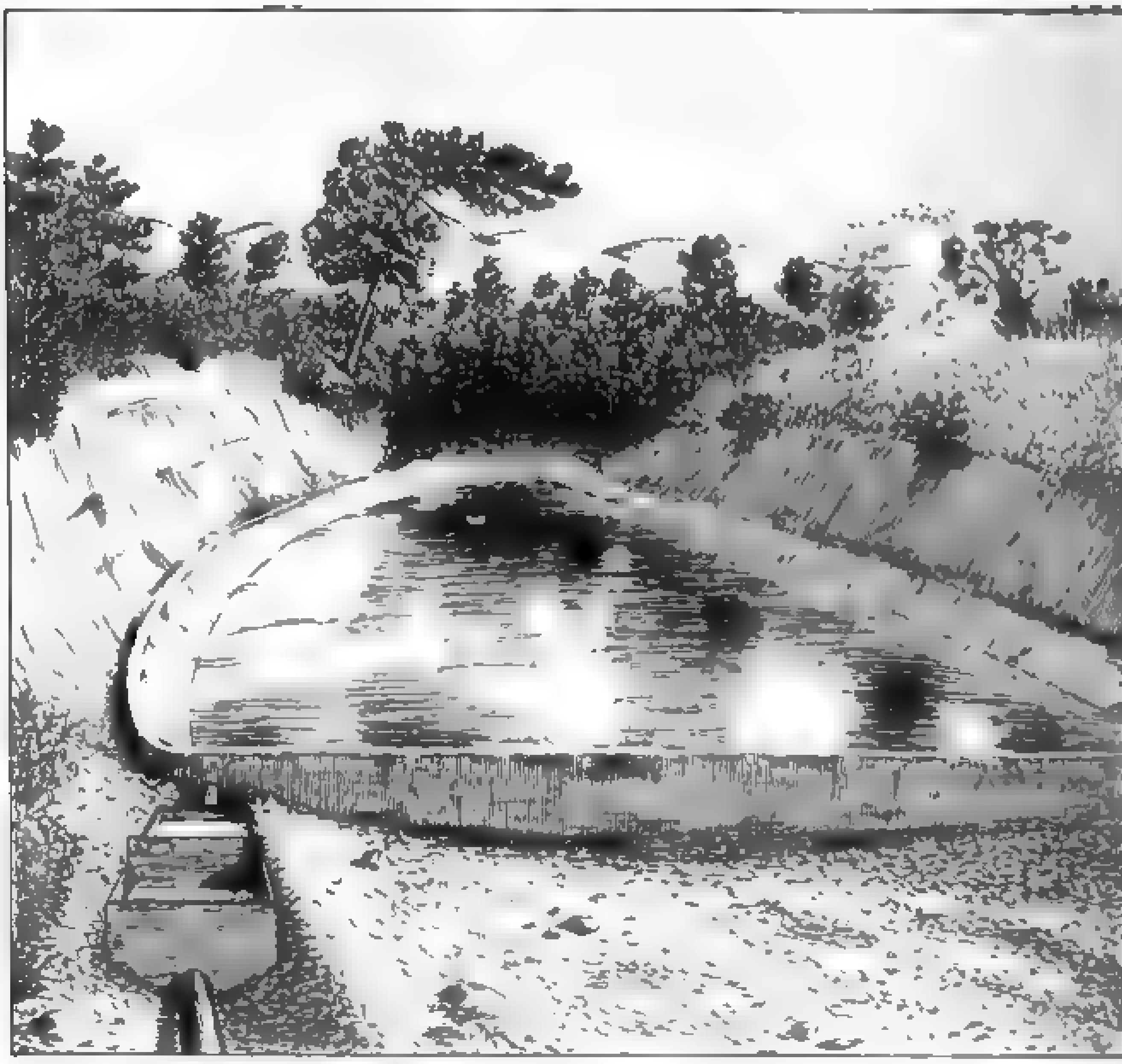

FIG. 1.—Cement reservoir for collection of water from a pumping plant, and its measuring box.

California well constructed small reservoirs, with concrete bottom and walls thoroughly plastered with pure cement, are frequent and are very satisfactory, though expensive. (Figs. 1 and 2.) Probably, however, a

FIG. 2.—Measuring box used in connection with distribution from small reservoir.

small reservoir which is most generally attainable and is easily home-made is a tank of dirt. The following is a condensed description of such a reservoir, by Theodore Sternberg, of Kansas:

A dirt bank and bottom is the best and least expensive of all substances from which to construct the pond. Surface soil is the best. Clay may do well for bottoms, but for banks it is useless, because, when the inner bank is exposed, clay at once cracks, but surface soil does not.

The very best shape for building easily and using horses and scraper is an oval, or at least rounded corners, the curve such that a team with scraper can easily be driven all around on the bank. Having marked out the extreme outside limits of the pond, if it be in sod, carefully remove the sod and pile it up out of the way, to be used later on. Then thoroughly plow the whole space where the banks are to rest, as well as the pond part; then, with cultivator, harrow, and garden rake, work down as fine as possible the dirt upon which the bank is to rest. Keep the team going over and over the bank foundation until it is fine and packed as firm as possible. If the banks are built upon the natural surface there is always a crack; the ground must all be worked for the banks, from the bottom of the pond up to the top.

The foundation of the banks being made, then, with team and scraper, move the plowed dirt from the bottom of the pond and dump it on the bank; start the bank 12 feet wide; for 4-foot banks 12 feet at the bottom is not too wide, and the top at the finish will be about 3 feet wide. As the dirt is dumped, spread each scraper load evenly; break up every lump, work it fine, and fill the tracks of the horses. This settles and packs the banks even and hard. The secret of good banks is the fining the ground and keeping it level as the banks rise, so that the whole is uniformly packed solid. The horses and heavy scraper do this all but the edges; pack the edges by walking back and forth, as in making a garden walk. The dirt from the first plowing being all removed from the pond and placed evenly all around on the banks, plow deeply the bottom, then, with harrow and cultivator, make this dirt as fine as possible to puddle the bottom. This bottom dirt being all fined to a depth of 8 inches, weigh down the harrow, put on your rubber boots, and turn on water; harrow, harrow, until this plowed ground is a thin paste. The bottom is made, and if the soil is loam the chances are that it will hold water.

Put in the sluice box or iron pipe through which the water is to be drawn, ramming well around it clay and chopped straw, so that not a drop of water can follow along the outside of it.

It takes time to make a pond. Even after this work has been done, time is required to settle and solidify bottom and banks. Therefore it is better to build the pond in the fall, so that it will be ready for use the following season. One of the very best ways to puddle the bottom of a pond is to keep the bottom damp and feed cattle in it for a couple of months. The balance of the banks may be finished at leisure. Use any kind of dirt which is most convenient for completing the banks; still surface dirt is the best for the pond and best to start grass on. When the banks are as high as the horses can readily walk on, then take the sod, if you removed any, or sod or stone, and build on the outside a wall 2½ feet high, fill in with dirt, and finish off the bank with the shovel. Be sure and not fill the pond up rapidly with water; fill it up 6 inches higher every day or two and draw it off; this is to settle and firm the banks. Until grass or plants can grow on the inner bank, to prevent washing down, have a lot of loose boards floating in the pond, and see to it that they are in position to break the waves when the wind blows.

Through the bank place a galvanized sheet-iron pipe to carry off the water when it reaches the height desired; put a joint in it at the outer end, to let the water down without being blown back against the bank, thus washing it away.

These definite details are given to show how easily small storage of water from any source of supply can be secured. The pond above described is about 50 by 55 feet and 4½ feet deep. Similar construction can be carried for a considerably greater area with safety and satisfaction. This reservoir is nearly all above the surface, because the water

was to be used close by on land of about the same level. Where the reservoir site is elevated, of course more excavation and less bank building can be employed, but the careful puddling is usually necessary to escape danger of leaking, unless a lining of asphaltum or cement is preferred.

TAKING THE WATER TO THE LAND.

Conveyance of water from the reservoir to the land to be irrigated is accomplished in various ways. The cheapest in point of first outlay, but in some respects the most wasteful, is the open ditch. If the distance be considerable, it is wasteful of water by seepage, wasteful of land, troublesome and unsightly in the rank growth of weeds, which, unless carefully cleaned away, ripen much seed for the water to spread over the irrigated land. Irrigation water vies with the wind as a weed distributor. Then, too, ditch conveyance depends upon the grade of the land to be traversed. If it is possible, loss of water can be reduced by paving the ditch with stones laid in clay, or it may be cemented, but still it lies in the way of cultivation and will vex the owner until he summons courage and capital enough to put in a line of "pump logs," or round tile, or cement pipe, or steel pipe sunk below the reach of the plow. Which will be best in land which freezes deeply local experience in water piping will decide. In the irrigated region this problem seldom intrudes, and all sorts of pipes are satisfactorily used. Riveted steel pipe, with size adjusted to the area to be irrigated, and with valves at the reservoir and at the discharge point, is the best arrangement. With such a pipe water can be carried over uneven ground by the shortest route and it will save a vast amount of loss and trouble. Of course all this is escaped if the reservoir be situated at the highest point of the immediate tract which is to be irrigated, but there may be many reasons for having it at a distance.

DISTRIBUTION OF IRRIGATION WATER.

The distribution of water on land to be irrigated involves a certain amount of engineering. The laying out of a system should be done by a competent surveyor who understands the regulation of the fall of the ditches according to the soil to be traversed, the volume and character of the water to be carried, etc., and the levels along which it can reach the different ridges by which it can be handled on the different irrigation faces, if the surface be somewhat uneven or rolling. It will not pay to guess at any of this work. It should be well done at first. There have been many instances of loss through wrongly located ditches. Some of the earlier systems somewhat hastily laid out have left so much land above the ditches, by giving the water so much more fall than necessary, that practically a new system has been laid out above the old one by carrying the water higher up, as it should have been done at first. All such enterprises on considerable scale call for professional advice from irrigation engineers. Of course the same principles hold

in small distributions, but one need not greatly err in the application of them to small pieces of ground if he will take a little pains; consequently some suggestions will be offered.

There is little ground so nearly level that water will not flow over it in some direction, but the grade may change so that distribution should be arranged from different secondary sources, or if distribution be from a slight ridge water may be taken on both sides of the same source for the different slopes or faces which are to be irrigated. The eye can not always be trusted to determine these directions. The simplest sort of a surveyor's level can be used by a layman for this work, but it is also possible to do it with homemade leveling devices which should be on every farm for location of drains, irrigation ditches, private hillside roads, grading land, or anything of that sort. If these are not available the beginner can return to first principles and take along a little stream of water with a hoe, and note the line on which it moves without cutting or showing a disposition to back up.

Ditches, flumes, and pipes.—When the supply lines of the land are located the means of conveyance are next to be decided upon. The ditch is the cheapest and at the same time the most troublesome and wasteful of both land and water, as has been heretofore shown. Though the ditch is largely used in handling large heads of water for the quick covering of large areas by flooding, for the handling of smaller heads through longer runs for other methods of application the ditch is generally superseded by flumes or by pipes with hydrants, or by open pipes or troughs.

Flumes are sometimes V-shaped but are usually rectangular and consist of a bottom and two sides, as this carries the water in good form for frequent diversion and openings are more readily contrived. Some have gone to considerable expense to construct these flumes of cement, or flat stones cemented together, because of the imperishability of the materials. Some of these are very neat, but it is very doubtful whether, on the ground of durability, they are worth the cost. They are easily cracked and chipped in working the adjacent ground; it is much more difficult to arrange openings and to close them, and in regions of hard freezing they would probably prove anything but desirable. The decision of irrigators, generally, is that a well-made board flume is good enough and by far the most available and most easily repaired, but it is very important that the flume should be made of sound lumber of whatever kind is least liable to crack or warp in the locality and will have the longest durability under alternating wet and dry conditions. The construction of the flume, the grade, and the character of the openings will vary according to the method which is to be used in the application of the water. Constant attention should be paid to keeping the flumes in good repair and water tight, because a leaky flume is not only wasteful of water but is a menace to the thrift of adjacent trees by excessive moisture. Losses have occurred by carelessness in this matter.

Distribution through buried pipes and hydrants is satisfactory for flooding, or for use with closed hose and sprinkling attachments, but sprinkling is practically unknown in the irrigated region except for lawns. Even for small fruits and vegetables in garden practice surface distribution is found to be much superior to any imitation rainfall, in economy of water, depth of penetration, subsequent stirring of the surface to check evaporation, and the condition of the fruit itself. Dry air, dry surface soil, and ample moisture at the root are found by long experience to be ideal conditions for perfect foliage and fruit.

Distribution from hydrants with large open hose, or open galvanized pipe, to take the water to prepared basins around the trees, or to connect hydrants with small lateral ditches, etc., may often be economical of water and valuable in delivery at certain desired points, but little piping is actually used in the irrigated region except to convey water to points from which it is distributed by flumes, or small ditches. There are conditions, no doubt, in which a freer investment in pipe than is now made would be profitable in the end.

PREPARING LAND FOR IRRIGATION.

Having thus brought the water to the distributing points on the land to be irrigated, it is desirable to suggest preparation which will facilitate the ease and evenness of application to the whole of the land. This is done by grading—not by leveling nor by securing any given slope, but merely to correct elevations and depressions upon each slope or face over which any water is to be run. If this is not done there will be sags or swales in which too much water will collect and knolls or humps which will get only what they can secure by capillary rise, and not enough to bring out their proper production. Such work as this can be done quite boldly in the arid region, because the soils are usually deep and of uniform fertility to considerable depth. To plow and scrape off knolls into sags is a safe proceeding as a rule, though in exceptional cases it would uncover areas of infertile subsoil. In the humid regions, this can not, of course, be so widely undertaken, because the soils are more shallow and the subsoils more refractory and infertile, but so far as feasible the land should be graded. For a small irrigated area which is naturally expected to yield high value, it may be profitable to haul good soil in to help bring depressions up to grade, even if the knolls are left to do what they can without water.

Drainage of irrigated land seemed to be a foolish and wasteful conflict of policies when irrigation began in the West, but later experience has shown that unless the soil is very deep and loose and the irrigation wisely applied there is considerable danger of excess of soil water, which is ruinous. Even deep, loose soils may be practically submerged by seepage from leaky ditches and excessive irrigation combined, for there are large areas in California where before irrigation was introduced it was necessary to dig over 50 feet for well water,

but after ten years of irrigation the ground water rose within a few feet of the surface and made ponds and marshes in the low places. This rise of the ground water also brought up corrosive alkaline matters which work havoc beyond simple water injury. It is quite necessary, then, in many places to arrange drainage for irrigated lands, and especially where summer irrigation may be supplemented by copious rainfall. Lands which need drainage to dispose of surplus rainfall may doubly need it when irrigation is supplied.

Preparation of land for irrigation should also include deep tillage and subsoiling. This is also desirable upon other accounts as well, but with irrigation it is essential that every cultural effort should be made to promote deep penetration of the water and deep rooting of the plants.

METHODS OF APPLYING IRRIGATION WATER.

Methods of irrigation must vary according to the amount of water available, the soil, the lay of the land, the character of the crop, and there can be no best method under all circumstances. With the experience of half a century in California there have come to be a few methods generally recognized to be best, each for the conditions which govern its preference. As the writer is most familiar with these methods they will naturally be chosen for discussion, in the hope that information regarding them will at least be suggestive to those who may be contemplating work along irrigation lines in other parts of the country. Points of value in a method must include the following:

(1) Distribution of moisture evenly throughout the soil mass to as great a depth as possible, providing it does not sink beyond the reach of the plant by root-extension nor beyond recovery by capillary rise.

(2) Economy of labor both in aggregate time and in the feasibility of operating without employment of extra hands.

(3) Economy of water in the prevention of waste by overflow or evaporation or by rapid percolation, and in placing the water where it will do the most good.

(4) Leaving the land in the best condition for attaining with least labor a state of tilth which conserves moisture and at the same time favors thrift in the plant.

Whichever method most nearly attains these ends in a certain soil and situation is the best for that particular case. But no method attains them all under all conditions, and one has to judge which consideration can best be disregarded, as of the least importance, to secure other greater benefits.

PERMANENT DITCHES.

Permanent ditches are an old means of applying irrigation water. They are led out from the main ditch wherever the water will follow the hoe at about the right speed for lateral seepage in sufficient amount, and planting is done alongside about as far as the influence of the

water can be counted on. The chief claim of the method is economy of labor, and that was sufficient to sway the minds of its inventors in favor of anything. It gives a very uneven distribution of water, it wastes both land and water, and it does not favor soil-stirring and plant thrift. It has no standing at the present time except perhaps as a makeshift to grow a little stuff in a corner for home use.

FLOODING.

By flooding is meant surface flow with very little restraint or guidance. It is a very rapid way to get a good deal of water over the land, and sometimes rapidity is a ruling factor when one has only a short run of a large stream. It is cheap but proportionally disagreeable, because the irrigator has to work in the water and use all his strength and speed to help the water reach all points—which however it never does in equal volume. At best the surface is partly well soaked, partly dry places, and partly mud holes, and, when cultivation follows, the plow turns up dust and mud and good, moist soil in varying proportions. For grain or forage crops flooding may in some cases be a defensible method, but the check system is vastly better even if somewhat more costly. Flooding has cheapness and speed for its chief claims, and it sacrifices all the other points. It usually requires several hands—more or less, according to the head of water which is being handled.

Flooding the orchard is sometimes improved by turning a furrow on each side of the space between the rows and then admitting the water to one row-space after another. With this slight leveeing more even distribution is secured, for all the water has to flow in a thin sheet over the ground between the furrows and has a better chance to reach all points of the surface, and where the slope is very slight it will work fairly well. The furrows protect the base of the tree from contact with the water, which is a good thing. Where orchard land is kept under a cover crop which it is not desirable to disturb this method of irrigation may suit the conditions very well, unless the land is properly checked before the crop is put in, and if this is done it is not called flooding the land but flooding the checks, which will be described later.

Flooding in general is obviously adapted to land which will take water rapidly, because the run is short, and a short run on a close soil sends the volume of water across the lower edge of the field before much penetration has been secured. Flooding, therefore, is generally deceptive, and the land gets much less water than it seems to. It is directly opposed to the furrow system, which will be described presently. If that is attempted on land which takes water too readily it will get much more than it seems to get, because there will be no satisfactory lateral seepage, but too brisk vertical percolation, and water can not be carried far enough. A small stream will run directly to the lower strata and out of reach of the plant if the soil is deep and rests, as is often the case, on coarse sand or gravel. For such a condition of affairs the check system is better than flooding, as will be seen.

Water for flooding is diverted wherever desired from the head ditch of the area which is being irrigated. This is commonly done with a cut in the side of the ditch, using a portable cloth or iron dam to throw the water out of the cut. These contrivances are a great improvement over the old method of shoveling dirt into the ditch. Some make a series of wooden gates in the ditch which can be slid up to let out the water at intervals. Cement ditches and buried pipes with hydrants are also used for flooding. The capacity must depend upon the extent of the area to be flooded. Wooden flumes are also used, and they are very desirable because of ease of diversion, and with a good flume the head of water can be handled with fewer men.

CHECKS.

A modification and, in most respects, a great improvement of irrigation by flooding consists in the use of what are called checks. It is really flooding by the use of levees which check the movement of the water and restrict it to definite areas, thus giving the assurance that the water shall remain on this area until it sinks out of sight. It has certain manifest advantages: (1) It makes it possible to know that a certain amount of water has actually been applied, because it is easy to see the depth of water which has stood in the inclosure. (2) It enables the irrigator to quickly spread a considerable depth of water over the surface, and thus bring even moisture to soil so leachy that a small application would disappear vertically without lateral seepage. (3) It facilitates the use of a large run of water in a short time. (4) It gives satisfactory irrigation where other methods fail.

The development of the present systematic check system from its antecedent flooding system was gradual. It began with imperfectly formed levees made with the plow at irregular intervals, and subject to breaking away on the low side, because the water collected there, and left the high side out of the water and consequently less thoroughly soaked. To meet this and replace crude methods of handling water in filling checks, improvements have been made in the system until at the present time the levees are quickly, evenly, and strongly made by the use of special tools and methods, and the handling of water is so successful that the work can be most rapidly done with little chance of break or runaway water. It has become, in fact, a model of even distribution of water. It does, however, require the shifting of considerable earth, which has afterwards to be worked back to its place before cultivation of the whole surface can be undertaken, and as the ground has been so thoroughly surface-soaked it must be worked immediately upon the arrival of proper condition, to escape baking and a cloddy surface which is difficult to pulverize. Fortunately, however, the disposition to run together and bake renders the soil better adapted to the use of the small-furrow system which is the ruling method for such soils. All forms of flooding or checking of cultivated land succeed

best on a light, coarse soil which takes water most easily and suffers least from water standing for a time upon its surface.

Checks along contour lines are little used in fruit growing at the present day; they are specially adapted to the irrigation of alfalfa or grain fields. Where the grade is slight and uniform and the contour lines are nearly parallel some fruit lands are handled in that way.

The prevailing method of checking orchards is to disregard contour lines because the slight departures from the level can be easily met by a little increase in the height of the levee on the low sides. Levees are, then, usually made between the rows so that each tree stands in its own inclosure, though in some cases the checks are made larger. The size of the check obviously is governed by the slope of the ground. The success of the check system depends very much upon being thoroughly ready before the water is turned into the head ditch or flume. The proper thing to do is to plan the operation out well from start to finish and have the ground all ready. If that is done the amount of water each man will handle is very great.

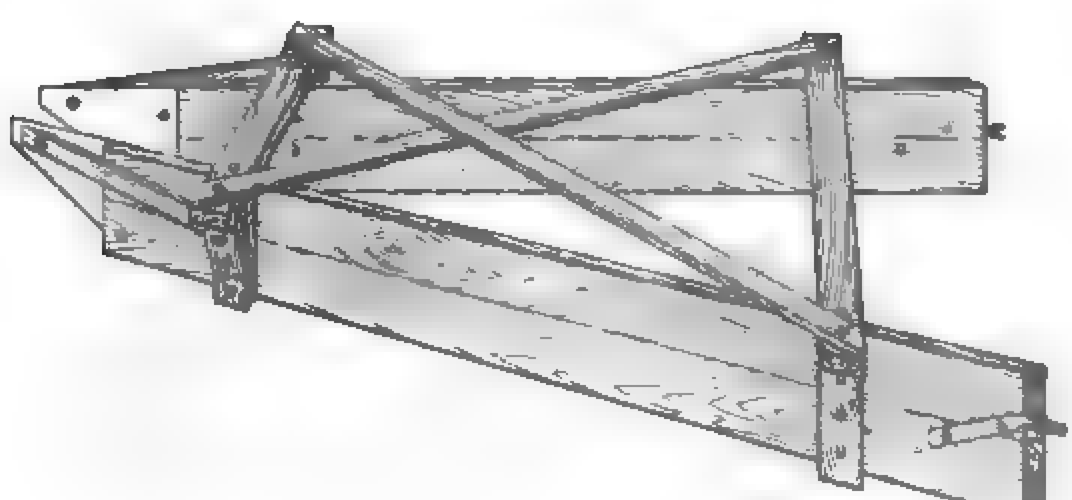

FIG. 3.—"Ridger" for levee making in the check system of irrigating trees and vines.

The first step after deciding how the water shall be run is to loosen the surface, both for absorption of water and to secure plenty of loose soil to make the check levees or ridges. The plow is often used. More recently the disk harrow, cutting a good depth, has become popular. Some work the whole surface of the ground, others only plow a few furrows or run the disks about where the ridges are to be made. If the soil is quite light and it has been kept well cultivated the latter method will do very well and save time if the checks are to be of good size. There is what is called "single checking," in which one series of checks covers the ground from the center of the interspace of one row of trees to the center of another; "double checking" is that in which two series occupy the same space, one series inclosing the trees, another being wholly in the interspace. Single or double checking depends upon the slope, the more rapid the slope the smaller and more numerous the checks needed to hold the water evenly upon the whole surface.

The ridges or levees are made very perfectly and quickly with three implements for horse use; the "ridger," the "jump scrape," and the

"crowder," which can be readily described. The "ridger" (fig. 3) is a sled with rather deep, solid runners made either of plank or sheet steel. These runners are set nearer together behind than in front, so that when moving forward the quantity of loose dirt taken in front must rise to escape through the narrow opening behind. The result is that when the man jumps on the sled and starts the team the runners sink in the loose dirt, and as it goes forward this dirt is left in a ridge in the wake of the sled. As the platform of the sled is rather high, because of the deep runners, it can be run again over the same ground and raise the dirt higher. In this way the chief work of the ridging is done by working from row to row of trees, back and forth, usually making first all the ridges which are parallel to the head ditch or at right angles to the flow of the water. When these are all made the ridger is started at one side of the land and the ridges at right angles to those first made are put in and the land is marked off in squares like a checkerboard.

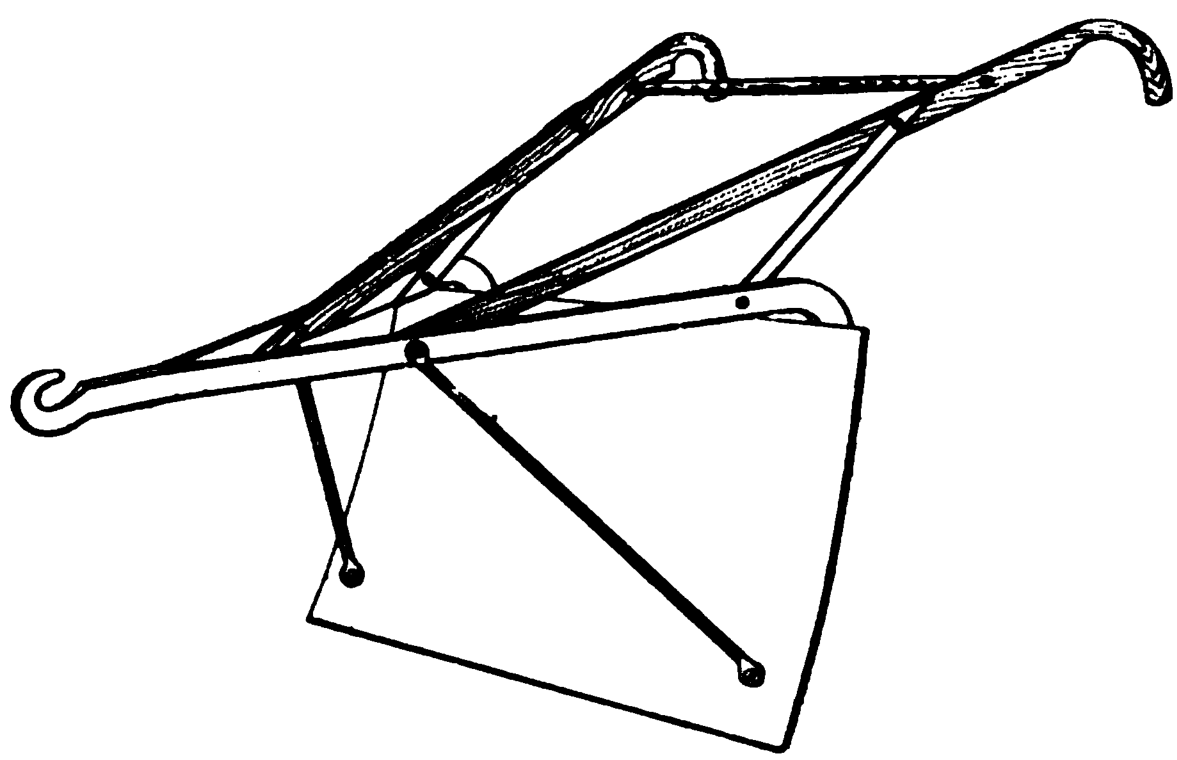

FIG. 4.—"Jump scrape" used to complete levees made by the "ridger" for the check system.

The checks are, however, not yet ready to hold water. Where the ridger has crossed the first ridges in making the cross ridges it has broken down the first, and the corners are therefore imperfect. Repairing of these corners was at first done by hand shoveling, but a labor-saving device called the "jump scrape" (fig. 4) is now widely used. It consists of a slightly curved plate of steel fastened to a standard with beam and handles like a light plow. With a light horse a man starts down through the checks close to the last made ridge, and as each corner is approached he sinks the handles so that the shovel plate takes some dirt, and at the right point he throws this dirt into the corner without stopping and proceeds, doing the same thing in each imperfect corner. After this very little is needed to make the checks all water-tight.

This covers the whole field with checks, or rather with square areas inclosed with checks or check levees. To handle water in this arrangement it must be turned into the highest check nearest to the source of supply, and when that is filled allow it to spill over into the next lower and so on, or else the water must be carried in a detachable pipe over all the checks to the lowest one (fig. 5). Fill that, take off a length of pipe, fill another check, and so on until the top check is reached,

the pipe being reconnected meantime over the next series of checks. This pipe method, using galvanized iron pipe with slipjoints, is very satisfactory where the grade is rather sharp and double checks are needed, and where allowing the water to run from check to check would be almost to invite a break away, or running the water down in a ditch outside of the checks would be likely to produce cutting and soil shifting.

Where, however, the grade is gradual, so that water even in a large stream can be safely let down in a ditch, the arrangements for filling the checks from a common source and not from each other is easily

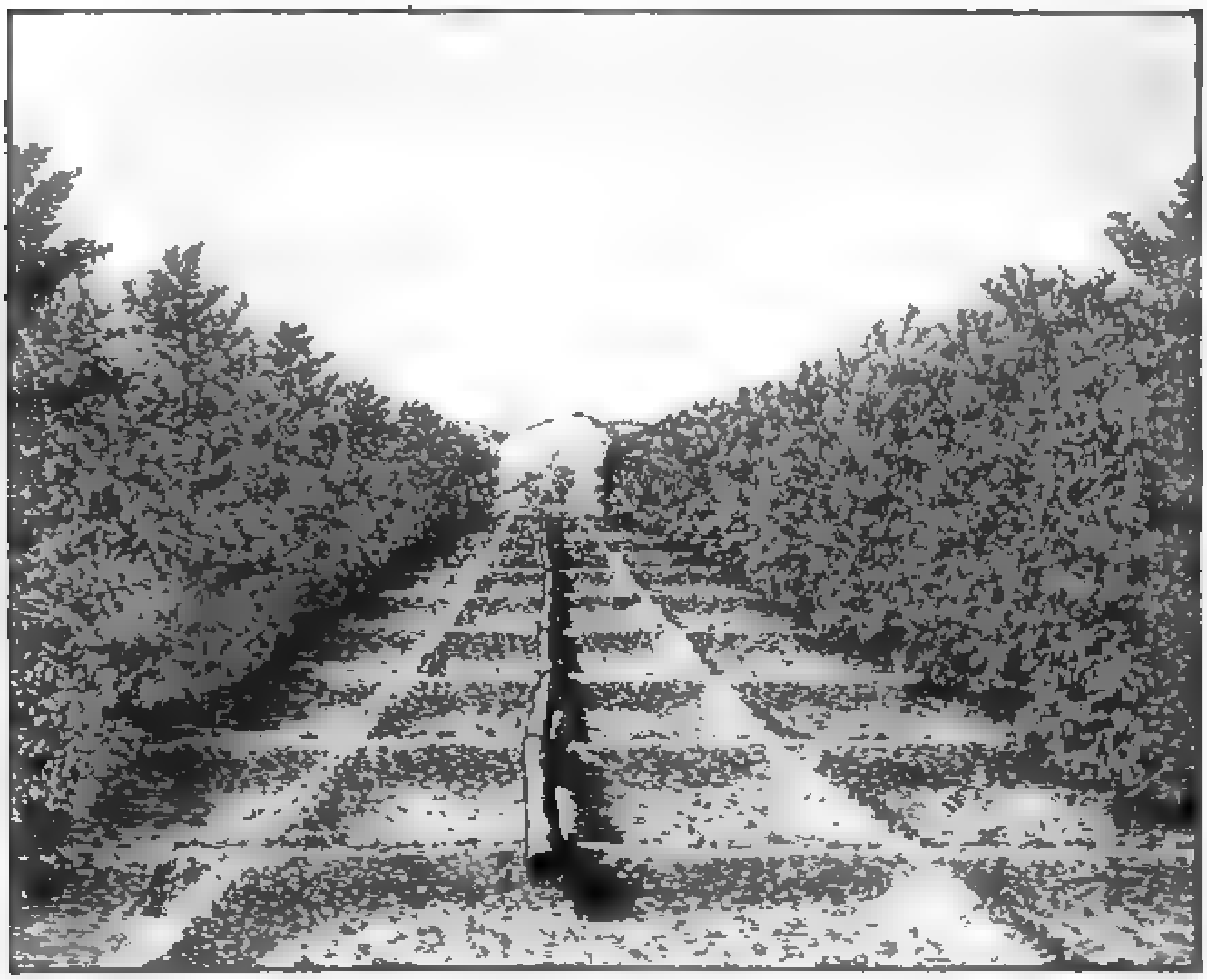

FIG. 5.—System of double checking and filling checks with detachable pipes.

made. Midway between the rows of trees the ridger is run twice on parallel lines a little apart. This makes two ridges near together which are easily made into a ditch by the use of the "crowder." (Fig. 6.) This is a V-shaped implement made of plank or iron, hitched to the horse by the apex, with handles from a crossbar, and usually having one long arm and one short one. It is merely a small, light form of the V-scraper, which crowds the loose dirt between the ridges to each side, thus clearing out and defining a ditch. The head of water for filling the checks is turned into this ditch, and as it reaches the two checks at the bottom it is let into one or both of them by cuts in the levee, and when these are filled it is diverted into the checks just above, and so

on until all are filled. Sometimes the highest check on one side of the ditch is opened, then the next on the same side, and so on to the bottom. Then returning, the checks on the opposite side are opened one after another from the bottom up so that when the last is filled the irrigator is at the highest point ready to send the water along the head ditch to the next series of checks.

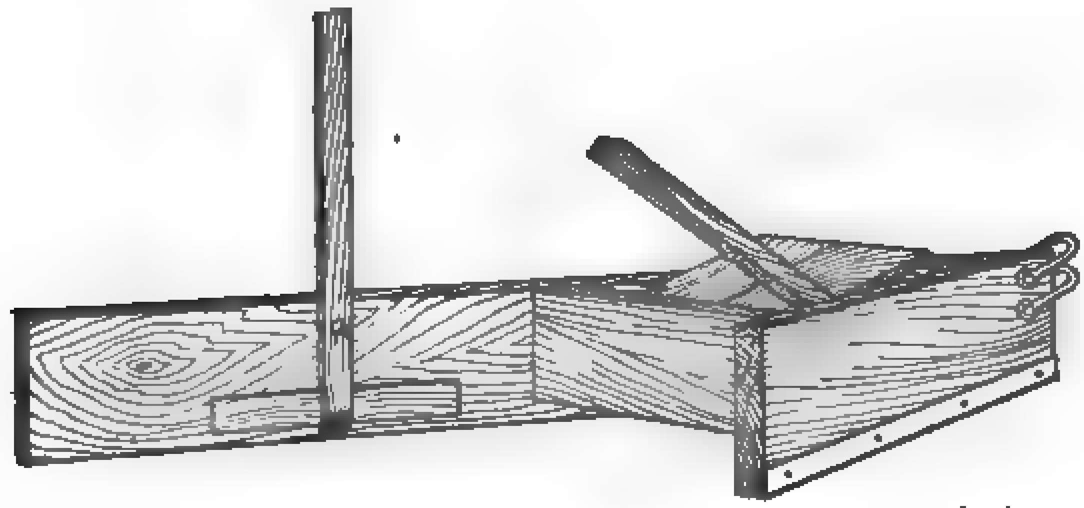

FIG. 6.—"Crowder" used in the preparation for distribution of water in the check system.

This is an outline of the work, enough, perhaps, to start a person of some ingenuity on the pathway of experience where he will learn many little and important things in the handling of water, treatment of levees, etc., all of which help to handle a stream of water without disaster but which can hardly be taught by descriptive words.

BASIN SYSTEM.

The system which has just been described, and which aims to apply water to the whole surface of the ground, is sometimes called a basin system because the water is held in small inclosures; but the writer is of the opinion that the term basin should be restricted to inclosures which do not aim at covering the whole surface, but only a small area immediately surrounding the tree. What has been called the check system is clearly a more rational and perfect method of flooding. The term "basin" will be used to signify a method which was apparently employed at first to escape the flooding system and to apply the water where it was thought to do most good. If this surmise is true the system is founded upon a misconception which has prevailed also in the practice of fertilization, that the tree derived its chief benefit from the soil immediately surrounding and beneath its bole, and that distant applications were likely to be wasted. Years ago it was held that the lateral root extension of a tree was equal to the spread of its branches, but recent investigations have shown that under favorable soil conditions the root extension is vastly greater. It is not reasonable then to restrict water or other plant food to the region chiefly occupied with the stay roots and not the feeding roots of the tree. Another error of knowledge and judgment as to the movement of water in soils was also involved in the early recourse to the basin system, and that was

that the water would remain in this region which was supposed to be of most service in the growth of the tree. No adequate knowledge existed as to the thirst of the encompassing dry soil and the movement of water by lateral seepage. It is true that one of the misconceptions or errors offsets the other to a certain extent and that the water did move toward regions away from the trunk and thus minister to the outer root extensions to a certain degree, but the mass thus moistened was in such small ratio to the dry mass surrounding it that the tree was inadequately served and was continually restricted in its growth by the heat, dryness, and impenetrability of the surrounding mass, and continually losing thrift by the extension of rootlets into a region of alternating drought and moisture. The teachings of experience and observation were, long ago, in support of application of water to the whole soil mass, except in very young trees, but even with these the moisture should considerably outreach the root growth until the whole is moistened. Even where the basin system is used, for reasons which will be stated later, it is still a frequent observation that basined trees do not do so well and that they show distress sooner than those under systems which secure more complete water distribution.

The basin system may be conceded these possibilities: (1) Trees may be grown on hillsides too steep for other means of irrigation unless the hillside be previously terraced; (2) the basins afford an opportunity to use a very small stream of water by allowing it to run for a long time in each basin, thus making a miniature reservoir at the base of each tree; (3) for young trees a small amount of water may sustain growth, while with other methods the same amount of water would be almost wholly lost by evaporation or percolation, or both; (4) the expense of wider application of water and the necessary after cultivation is obviated. Against these it may be urged that, up to a certain degree of slope, double checking will secure better saturation; that experience has shown it to be dangerous to the planter to grow many young trees on the expectation of greater water supplies to meet their later needs, unless he is fortunate enough to sell out to a tenderfoot before these needs arrive; that whatever outlay may be obviated by having the larger part of the orchard area unstirred is a heavy discount upon the future growth and productiveness of the trees, and that basining without cultivation brings the soil into a dense unaerated condition fatal to plant life as far as the water reaches, which subsequent cultivation rarely brings again into condition favoring growth. Basining differs from flooding and checking in this, that it counts on shaping the water receptacles not oftener than once a year, and too generally looks upon them as permanent structures. Still, it must be admitted that there are conditions of soil, water supply, and topography which give the basins standing as the best system available under the circumstances.

In planting on hillsides, terracing is the foundation of the basin system. Terraces are plowed and scraped out until they have width enough to accommodate a line of basins and a ditch at the foot of each

bank to supply them. The terraces are given a little fall, alternating in direction, so that the water, starting from the ridge above, is dropped through a box, or otherwise let down, from the low end of one terrace to the high end of the next, and so on until the stream reaches the bottom of the slope. As a basin is reached it is filled and closed and the water sent along to the next and so on. As these basins are usually small and shallow they are filled two or three times in succession at each irrigation.

Terracing in an arid region is attended with objections other than the cost. The banks are bare through the dry season, except as they may be tenanted by unhandsome drought-proof weeds, and are very different in appearance from the grass-covered slopes of the humid region. Nothing can be grown upon them except at too great cost of labor and water. Then, too, the area of hard surface occasions a great loss of water by evaporation, so that even irrigated trees may be stunted by drought. The soil of the banks, unrestrained by turf, is often cut and washed badly by heavy rains, and then fills the ditch and basin below and occasions considerable repairs. Wherever water can be handled in contour ditches or furrows, terracing should seldom be undertaken for commercial purposes.

With slopes which do not require terracing, basins on the steeper parts are largely made by hand labor, after plowing to loosen the whole surface, and the operation consists in moving the earth from the upper side of the tree, so as to form a circular levee on the lower side, until the tree stands in a level, roundish pan as large as can be made without too much excavation and filling. As the slope becomes less the basins enlarge and reach a diameter, finally, where the sides can be made by turning a small horse or mule around the tree with a plow, the rim being further raised and shaped by hand so as to hold 3 inches or more of water without danger of breaking away.

The basins are filled with a small stream by ditch or hose or pipe line, according to the ground and notion of the irrigator. They are filled at such intervals as the water supply admits or the growth seems to need. The basin bottom is rarely disturbed. The cracking soil is finally given another dose of water to close up its wounds; meantime the frequent surface soaking puddles the soil and the condition unfavorable to growth arrives sooner or later, according to the disposition of the soil to run together by water settling. Drying and cracking is lessened by filling the basin with manure or rotten straw or other light rubbish, or by a layer of coarse sand on the bottom. As the tree grows the foliage shades the basin and thus reduces evaporation.

LARGE-FURROW SYSTEM.

Next in order, perhaps, to the systems which involve levee construction should come the more or less permanent waterways near the trees, which may be considered one phase of a furrow system. (Fig. 7.) In one form it is a very old method, viz, taking out water wherever it

would follow a furrow at the right speed and planting adjacent ground, relying upon the seepage from the ditch thus marked out. This has been discussed already. A method which perhaps belongs to the same class, and yet is as marked an improvement upon its prototype as the check system is upon flooding, is the large-furrow irrigation. It has two main divisions, the contour ditch on hillsides and the mid-row ditch on the level. They both act by seepage, as did the old permanent ditch, but they differ from it in being frequently broken up by cultivation, which removes the chief objectionable feature of the old ditch.

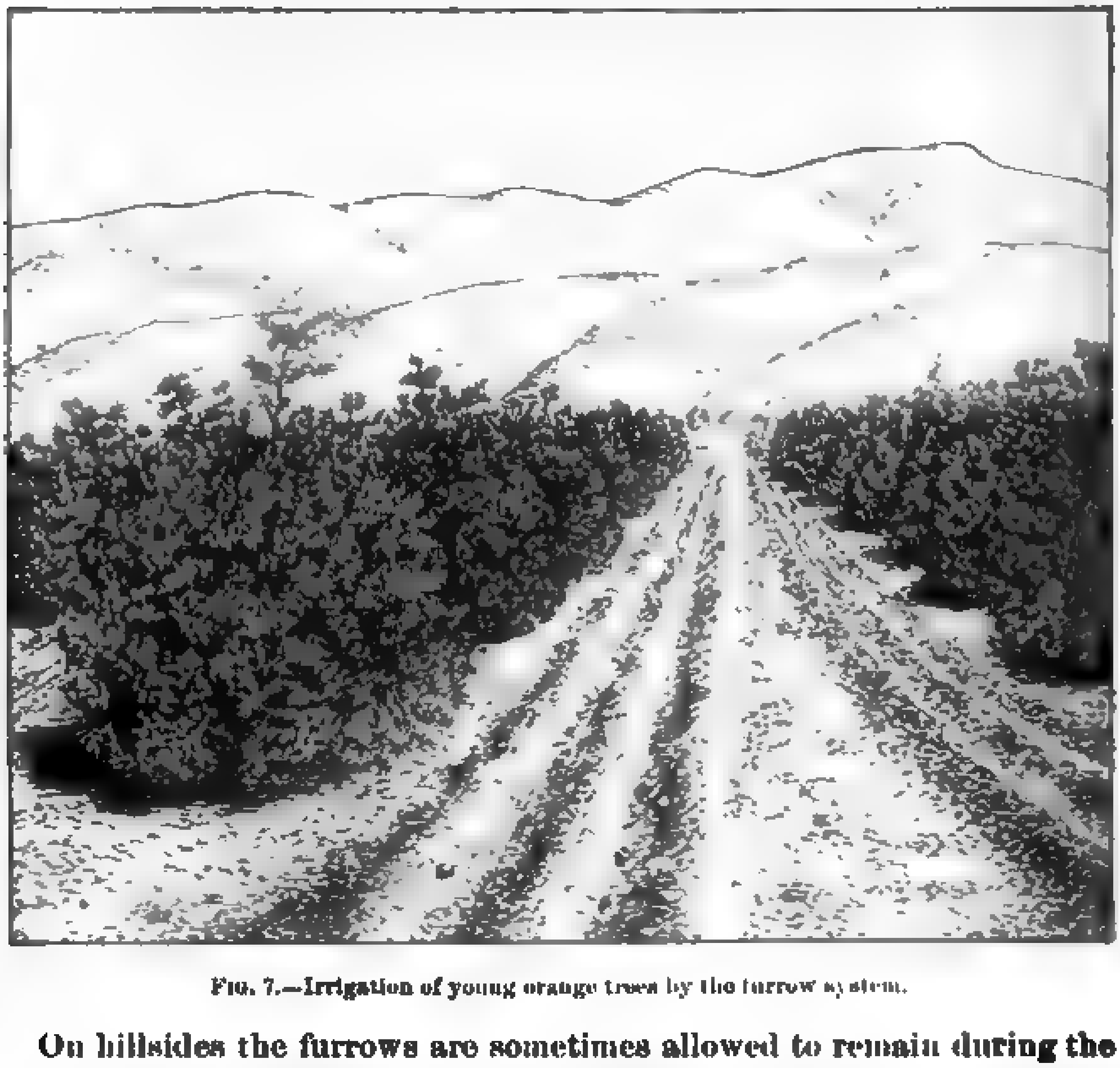

FIG. 7.—Irrigation of young orange trees by the furrow system.

On hillsides the furrows are sometimes allowed to remain during the rainy season, because they offer a convenient way to carry down storm water and prevent cutting, but they are thoroughly obliterated by the spring plowing and cultivation, and reopened when irrigation must begin, about two months later. The new furrows will probably not occupy the same ground as the old, for the line may start above at a different point, and in the rough leveling, which is done partly by the eye and partly with the surveyor's level or the triangle, there will be considerable variation from the previous season's locating. The locating is approximately on contour lines, but with such fall therefrom as will carry the water without too much speed and facilitate turning at the

boundaries of the area being irrigated to deliver the water into a lower furrow which recrosses the irrigation surface. Thus, the general plan is an irregular zigzag by which the water passes from the supply at the top of the slope to the outflow at the bottom, running slowly enough to saturate all the soil to the bed rock, which is usually not far below, and which assists in the lateral distribution by the underflow along its surface. Sometimes the water is let down by a zigzag on each side of the irrigation face (irrigated area) and furrows connect one zigzag with the other, the outflow from a higher area being caught by a zigzag on a lower face and thus distribution is accomplished over hillsides with several differing slopes.

The efficacy of this single furrow or ditch is due to the fact that the bed rock prevents the escape of the water downward and the slope of the rock promotes lateral distribution. In some cases, also, the bed rock consists of plates standing on edge, between which excess of water sinks and the roots follow it. Where the rock is a flat plate at small incline there is sometimes injury from accumulation and retention of water, and drainage is necessary, while a comparatively short time thereafter irrigation is again necessary, because the shallow layer of soil can not long hold water against capillarity and evaporation, even though the surface cultivation may be good. The furrows for this style of hillside irrigation are usually put in with a double-moldboard plow, following a line of stakes previously located. On regular slopes the trees could be planted approximately on contour lines to facilitate this annual furrowing, but for the purpose of having the trees equidistant, to evenly divide the ground, and facilitate cultivation, the planting is generally done in equilateral triangles. When the furrow is put in for irrigation it may follow a line of trees for a time and then shoot across the row, one way or another, to follow the grade desired for the water. It does not matter much to the tree where the ditch runs, for the whole ground is to be saturated in the way described above.

The point of greatest difficulty in the use of this system is to secure a good turn for the water at the end of the grade. The turn is often quite sharp and the water is liable to cut. This is sometimes prevented by spreading pieces of old sacking over the dirt and sometimes a bunch of swale hay or other fibrous material bedded in the turn holds the soil fast. When the waterways are thus well fixed, after the rains are over and the starting of weeds is very scant, the orchard may be left without further cultivation for the balance of the season, water being applied to the ditches once in two or three weeks, according to the ascertained needs of the trees on the particular location and soil involved.

Large furrows on level lands are chiefly used where only a few applications are necessary and the trees are of sufficient age to occupy all the ground. To interfere then as little with the cultivated surface as possible deep ditches are plowed out midway between the rows and a good deal of water is turned in to fill all these ditches. As the water

sinks away they are refilled to whatever amount the trees are thought to need, either for enlarging the fruit or for continuing the late summer growth. This method of applying water is chiefly used for deciduous trees wherever a limited amount of irrigation is required to supplement rainfall and not where systematic irrigation is the chief dependence. For lands which take water quickly this method is believed to foster deep rooting and for old trees it seems to serve an excellent purpose. It requires a considerable volume of water, such as can be had by pumping from rivers upon the orchards near the banks or from capacious wells elsewhere. It requires vastly less work than checking, both in preparation of the ground and in subsequent cultivation.

The large furrow method prevails with small fruits, and where the ground is level is used for certain distances with outward and return flow in alternate rows, the furrows being deepened enough at opposite ends to allow of a slow movement of the water during which seepage saturates the slight ridges between the furrows, upon which the small fruits are set. If this is not admissible the furrows are each given water from the flume or head ditch at one end until sufficient saturation has been reached.

SMALL-FURROW SYSTEM.

This is the most popular of all systems in California, and would be almost universal if it worked well in all soils (which it does not). It requires land in which vertical percolation is not excessive and lateral movement is adequate. Its unit is a small rill of water running for a long time, filling the ground, which, while it becomes gradually saturated, still allows the small surplus to continually proceed. The irrigation is accomplished by multiplying these rills, each doing its own work, with the result that as they all reach the bottom of the grade the whole area is deeply and thoroughly soaked. If properly done no water has flowed over the surface and it is possible also to so regulate the water that very little flows away at the lower end. This result is impossible on land that swallows up a small stream so that it might run for days and never gain more than a few feet of distance. It is also impossible upon a grade over which water, unchecked, could flow without penetration. Where a small stream of about a gallon a minute will run so slowly that, always losing water and yet never being itself lost, it will follow a furrow something like 40 rods in about twenty-four hours, the soil and the grade are both suited for this method of irrigation. Of course the size of the stream must be adjusted to the soil and the slope, but the general measure given contains a rough indication of fitness.

The advantages of the small furrow system of irrigation for land which it is intended to keep with a bare surface frequently stirred, will include the following: (1) It thoroughly soaks the ground and accomplishes even distribution without saturating the surface. By the water drawn up from the little stream in the bottom of the furrow the surface soil is fully moistened, but does not run together as it would with

water standing upon it; (2) the displacement of the soil is reduced to a minimum, consequently the labor is also thus reduced, and the cost is less than of any other method which distributes so evenly and thoroughly; (3) there is no reflection of the sun from a water surface and no excessive collection of water at the base of the tree, or contact of standing water with the bark, all of which are believed to be causes of injury to the tree; (4) with the surface well prepared the distribution is almost automatic and may be left to itself for hours if necessary; (5) cultivation after irrigation can be begun sooner and the land brought to fine surface tilth at less cost than with any other system which would give equal moisture to the same kind of land.

Application of water by small furrows is greatly facilitated by special arrangements which are now almost universally used in California orchards worked by this system. One is the arrangement of the flume which is to feed the furrows and which extends along the high side of the area to be irrigated. These flumes are made either of

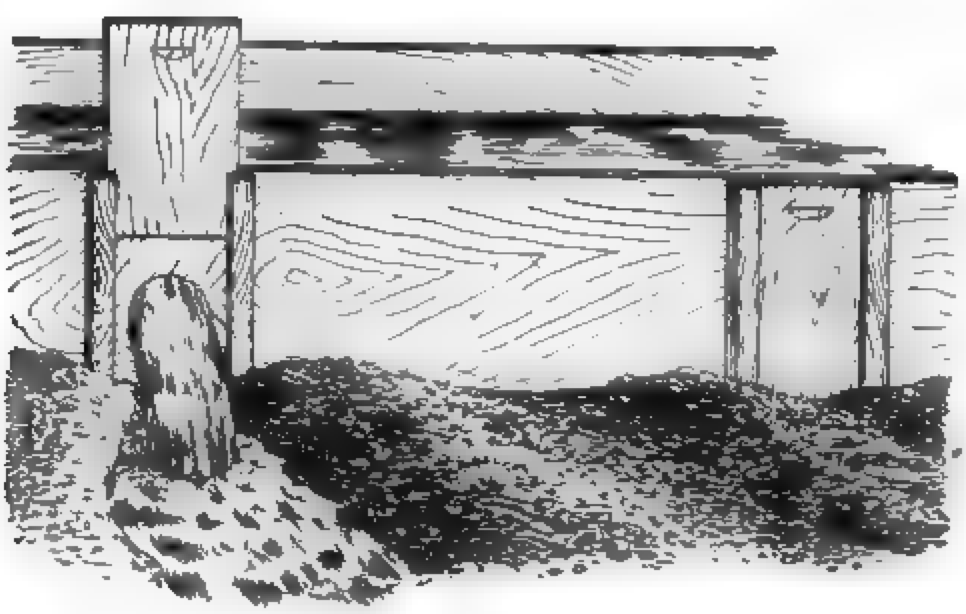

FIG. 8. Flume for distribution of water in the furrow system.

cement or boards—the latter generally preferred, because easily made and being but partly below the surface, can deliver water to the furrows more easily than a cement ditch nearly flush with the ground surface; besides, openings and gates to adjust the amount of water allowed to escape are more easily contrived. Two things are essential to the even delivery at all openings of the same size: First, the flume should lie nearly level, using a drop now and then as necessary; second, the sides of the flumes should be all of the same height, so that there shall be the same water pressure above the center of the openings, which are round holes bored in the sides at a uniform distance from the bottom. If the flume is decreased in size as the distance increases from the starting point, make it narrower on the bottom, not lower on the sides. The round holes are usually opened and closed with metal slides moving in metal cleats tacked to the outside of the flume. These gates are best on the outside, because they are less liable to catch loose stuff in the water and they are more easily adjusted than if in the water on the inside. (Fig. 8.)

A good size for flumes is a uniform depth of 7 inches and widths varying from 16 to 8 inches. Two inch holes are good for the exits, though some use smaller. The distance between the holes will of course be the distance which is chosen as best between the furrows, which is usually about 2 feet. With young trees it is common to use fewer furrows and run them near the trees. As the trees spread, more furrows are used until the whole space between the trees is furrowed, except that the water is not brought as close to the trees as at first.

The furrows were made at first with a small single plow, but later several plows were attached to a frame, and now the "furrower" or "marker" consists of a frame carrying four or more plows, with two good-sized wheels several feet apart on a shaft ahead of the plows to steady them and regulate depth. The furrows are led up to the holes in the flume and the water is started.

There is a great deal to be learned by experience in handling water in the furrows, as by other methods. It is important that the lands should have equal areas; that the surface should be free from depressions, for there the water will collect until it rises above the furrows and finally runs together in a pond. The directions in which the furrows are run depend upon the degree of the slope: sometimes straight away from the flume; sometimes diagonally through the rows, giving less grade and allowing the water to soak in better. The admission of water depends upon the character of the soil. If it is light and coarse and takes water a little too fast, a large stream will rush through, carry off much soil, smooth the sides of the furrow, and make percolation less rapid afterwards; while on a rather heavy soil a strong rush at first would almost cement the sides so that there would not be soaking enough. Sometimes a larger stream may be given after the ground is wet than at first. After the small stream has reached the end a still smaller stream from the flume is continued for twenty-four hours or more. These are manifestly things that must be learned largely from experience and observation on the spot.

The water is controlled by regulating the slides in the flume, closing them down as nearly to uniform openings as possible. Some are able to do this so skillfully and to so gauge the stream to the receptive character of the soil that very little will waste at the lower ends of the furrows. This is, however, rather exceptional, and it is found that there will either be quite an outflow or that the trees at the lower side will not get enough water. Naturally the trees near the flume will get most water, as all the water goes by them and least of all passes the trees at the other end. To prevent loss, then, and at the same time to give the lowest trees more water it is common to put in a few large furrows across the lower end into which the water will run and soak away; or, what is perhaps better, the few rows at the lower end are checked and the water thus collected. Some arrange to have an alfalfa patch below the irrigated area, so that overflow water is turned to good account.

The small-furrow method on land adapted to it is used for everything which can be profitably grown in rows and cultivated after irrigation. All kinds of small fruits, vegetables, and field crops are thus open to the system, the number of furrows depending, of course, upon the distance between the rows and the degree to which the soil favors lateral seepage.

SUBIRRIGATION METHODS.

Introducing water below the surface to escape all the objections which may be urged against prevailing irrigation methods has long been the subject of invention and investigation. There is also a warrant for the effort in the fact that there are very large areas of profitable land in the irrigated region which are subirrigated either by natural underflow from adjacent higher grounds or from rivers or by artificial underflow from adjacent irrigated lands or the leaky ditches which supply them. The frequent mention of these situations as "subirrigated" has created the impression in distant parts that California was quite extensively using a subirrigation system. It is a misapprehension. California inventors have fitfully labored with the proposition for the last twenty-five or thirty years, but the matter has not yet passed the experimental stage and the acreage irrigated in this way is insignificant.

Subterranean distribution of water has, however, such obvious theoretical advantages in preventing loss by evaporation, in distributing water at a level which should encourage deep rooting, in reducing the frequency of surface cultivations, and possibly in automatic distribution of water which should be vastly cheaper than any kind of surface flow, that interest will always pertain to the proposition and efforts will be continually put forth to give it practical realization. For these reasons a brief characterization of subirrigation systems which have come under the observation of the writer will be given:

About twenty years ago the so-called "Asbestine system" was devised. It consisted of a farm reservoir in which water was collected to furnish a certain amount of pressure throughout a system of jointless pipes laid in trenches of suitable depth at whatever distances apart were determined by the facility with which water would seep laterally through different soils. These jointless or continuous pipes were made of cement and sand by a machine traveling in the trench, and this was resorted to to preclude the entrance of roots to the pipe, which was found to be an objection to the older systems of perforated tiles. At proper distances openings were made in the top of this pipe and a cement standpipe of larger diameter was saddled upon the continuous pipe at each of these openings, the standpipe rising to the surface and having a cover. When the water was properly admitted to the system from the reservoir it flowed in about equal volume from all the openings, soaked away at the bottom of each of the standpipes, and when

the supply was shut off and the water disappeared at the bottom of the standpipes the roots could not reach any water that might remain in the pipes because of the air space surrounding the opening secured by the presence of the standpipe. Some experiments with this system were made but the cost of construction was seen to be so great that interest in it speedily declined. No demonstration was had that the system, properly constructed, would not successfully distribute water underground: in fact, enough was done to show that it would do so, and it is an interesting fact that in one case a small acreage thus piped was allowed to go unirrigated for a number of years because rainfall seemed ample for the growth of fruit, and was again irrigated by the system when a year of very short rainfall brought distress to the trees, showing that it remained free from roots. Still the cost of the system remains an apparently insurmountable objection to its introduction.

A system of distribution has been proposed which differs from the foregoing in placing the standpipes below the supply pipes and bringing the whole distributive system below the reach of the plow, which is an advantage in point of cultivation and a disadvantage in difficulty of seeing what is going on. The author of this system proposed to use tile to conduct the water from one of his standpipe cisterns to another, and trusted to their drying out between irrigations to remove all inducement to root entrance. He prescribed more pipe and more outlets than were contemplated under the earlier system, and would presumably get a better distribution of water, but the larger amount of cement construction and of excavation would probably make this system even more expensive than its prototype.

A system of similar aims, which has been patented, uses water from a reservoir through a system of iron pipes laid beneath the surface. At suitable distances the pipe has small holes on the under side; beneath each hole is a cast-iron chamber open at the bottom, and around this casting is a gravel pocket into which the water will flow and from which it will readily soak away into the surrounding soil. To irrigate trees of any kind a line of pipe is laid along a row of trees about 2½ feet from the trees, and opposite each tree a gravel pocket is made, and each one of these pockets holds about 5 gallons of water when full. When the water is turned on it continues to flow until the water pressure in the gravel pockets is equal to the pressure from the tank or reservoir, and then the water ceases to flow, only as the ground absorbs it. This system also occasions large outlay for materials and labor.

In another system of subirrigation three quarter inch pipes of iron carried the water to 2-inch iron standpipes, or hydrants, fitted with valves or plugs to regulate the flow. The water issues from these stand pipes through small perforations in the sides. The entrance of roots to the pipes is prevented by the fact that when the valve below is closed the interior of the standpipe becomes dry.

Dr. S. M. Woodbridge, of Los Angeles, has in use an outfit which is less expensive than the foregoing system, because valves are discarded for slots cut in the stand pipes through a part of the threads which connect it with the T in the main pipe. Partially unscrewing the standpipe opens these slots and releases the water, and screwing it down again not only closes the slots and stops the water, but cuts off any roots which may be entering. Both systems rely for distribution of water upon a small release at a central point equally distant from four trees. Theoretically the objection would be that the supply would be too slow and scant except in very open soils, and in such soils there might be too rapid leaching away of the water to moisten the soil horizontally. On heavy soils lateral seepage from perforations, half the distance between the standpipes, say, 10 or more feet, could hardly be expected. Being automatic, however, and acting through a long period of time, if one has a suitable reservoir, there might be satisfactory amounts distributed in all except leachy soils.

The same comments would apply to the use by Dr. Woodbridge of a long line of iron pipe laid along the surface, with small openings at intervals discharging a trickle of water into each of a series of spade-holes placed in the center of the squares formed by four trees. By regulating the flow each hole can have just what will soak away without overflow. This is, however, really a very small basin system, with the basin placed as far from the tree as possible, which is a good place for it providing the water moves well laterally, and is sufficient in amount.

Thus far attention has been given to deep systems of subirrigation, such as would benefit the growth of trees. There are fewer difficulties attending such shallow system as might best serve gardens and small fruit plantations. There is reason to believe that, on certain soils, distribution through simple lines of tile laid near the surface may be more satisfactory than running water in furrows. This will be for shallow-rooting vegetables and berries, where the pipes are to be relaid and thrown out at short intervals of time. The entrance of roots in such cases is not a ruling factor. The distribution by connecting these lines of tile with a head ditch or flume is easily effected, and shallow cultivation need not be interfered with. But even in such case the cost of tile enough to cover any considerable area soon reaches high figures, and the labor of laying and relaying it is also expensive. It is doubtful whether the time will ever come when such systems and devices will replace well-regulated surface distribution and the cultivation which is associated with it, though for economy of water, and to escape the refractory condition which some soils assume upon surface irrigation, experimentation in this line certainly commends itself.

Distribution through tile laid upon the surface is available for shallow-rooting plants, and has been shown to be economical both of labor and water.[1] In an arid region, however, the prevention of surface stir-

[1] U. S. Dept. Agr., Farmers' Bul. 56.

ring of the soil is a decided objection to the system, unless the soil be very light and free from a tendency to bake. Surface applications not followed by stirring are not a substitute for cultivation, as already insisted upon in another connection. It is a common experience of beginners that plants may dwindle and fail, though water may be almost daily poured around them, on an uncultivated surface. Each new application seems to add to the compact and inhospitable character of the soil.

HOW MUCH WATER IS USED.

Thus have been hastily sketched the different ways in which water is applied to fruit trees in California, and it is hoped that this will be found suggestive to beginners in other parts of the country. A very interesting question is, How much water is used? It has already been claimed that this question can not be answered categorically because of the differences in exposure, soils, rainfall, and in the requirements of different plants. A careful inquiry recently conducted by the writer included the experience of scores of irrigators in different regions of the Pacific coast, and disclosed the fact that the amount of water applied actually differed even more widely than the theoretical computation based upon the influence of the variable factors mentioned would indicate. It is found that in addition to topography, mechanical conditions of soil, and variation in plant requirements, and at the same time somewhat determined by them, the factor of frequency intrudes, and, upon consideration of all factors, these brief deductions are suggested:

(1) With adequate depth and retentiveness of soil, 20 inches of rainfall, if duly conserved by good cultivation, may render irrigation unnecessary for deep-rooting, deciduous fruits.

(2) If the rainfall on such soil is inadequate it may be satisfactorily supplemented for such plants by winter irrigation, using a total depth of 6 to 12 inches, in from one to three applications, according to the receptivity of the soil.

(3) Also, for such soils for such plants, the same results can be secured by summer irrigation with from 3 to 6 inches of water, divided into two or three applications.

(4) On deep, leachy soils for such plants neither heavy winter rains nor winter irrigation will suffice, and a monthly application of 2 or 3 inches of water from May to August or September may be required.

(5) Even on deep, retentive soils, as well as on coarse soils, shallow-rooting deciduous plants, including what are called "small fruits," may require fortnightly or even weekly applications amounting to 4 inches a month during the dry season.

(6) On shallow soils of [illegible] character even deep rooting trees may require 2 [illegible] from May to August, while on shallow, coarse soils 50 per cent [illegible] necessary.

(7) On shallow [illegible] rooting small fruit plants may fail through [illegible] of any frequent use of water

which is commercially practicable. Sprinkling and mulching may make the plants satisfactory for home use.

(8) Evergreen fruit trees, including citrus fruits, require about 50 per cent more water than deciduous fruits would require upon the same soil and in the same location, except that the olive will thrive with approximately the same water which satisfies a deciduous fruit tree, but it must be available later in the season, as the tree develops its fruit later.

These deductions are not intended to be indications of what is necessary to the trees; the quantities given are general statements of what is used by those who have bearing trees and secure good crops of marketable fruit.

AFTER TREATMENT OF IRRIGATED LAND.

In most parts of the irrigated region clean culture is practiced during the growing season, though there is another policy which seems to suit local requirements better in some regions, as will be noted presently. This clean culture is undertaken for two main reasons. One is moisture conservation, which has been pointedly suggested in the previous discussion of the interrelations of irrigation and cultivation. Cultivation is undertaken, then, to reduce the irrigation requirements; to retain the added moisture for the use of the plant. Experience amply teaches that this is successfully done, and investigation has given accurate measure of conservation, both as against evaporation and against exhaustion by the roots of weeds and intercultures of crops.[1] Just as barely adequate rainfall may be rendered amply adequate by clean and frequent summer cultivation, so irrigation water may be reinforced in the duration and sufficiency of its effects by the same policy.

But another and important office of cultivation in connection with irrigation lies in the maintenance of a condition of tilth which facilitates a proper degree of aeration and free root extension. Irrigation, even in its wisest application, has a tendency to compact any soil which is capable of compacting, and few can defy water settling. Compacting promotes evaporation and subsequent sun heating, and the resulting dryness and undue heat, as well as the density of the mass itself, restrains root development. Consequently it is a universal conclusion that, with a bare surface, soil stirring must follow irrigation just as soon as the soil comes to a good working condition. What the cultivation shall be depends upon the nature of the soil. Winter irrigation is almost always followed by a good plowing, and by a good harrowing also, unless considerable rainfall is to be expected afterwards. Summer irrigation is followed by stirring with whichever of the many forms of cultivators is found by local experience to be the

[1] U. S. Dept. Agr., Farmers' Bul. 87.

best pulverizer for the particular soil, and which secures, with the least labor, fineness to an adequate depth, for it is plain that in the thirsty air of the arid region the earth mulch must be somewhat deep, as well as fine, to protect the firm layer from loss by evaporation.

COVER CROPS IN THE IRRIGATED ORCHARD.

Successful irrigation is not conditioned upon clean cultivation; in fact, it may be quite otherwise. Cover crops are sometimes of advantage. Recent practice in some parts where irrigation water is abundant beyond the requirements of the trees, is to grow alfalfa in the orchard. Being a deep rooting legume, it may be of advantage to the trees in the presence of ample moisture, while with scant moisture it would rob the trees and practically ruin them. In the hot irrigated valleys of Arizona a cover crop of alfalfa reduces the soil temperature, prevents the reflection of heat which occurs from a light-colored soil surface, and is said to insure thrifty young trees where clean culture destroys them. In cooler parts of the arid region, as in the mountain valleys of northeastern California and in Idaho, alfalfa is also grown in irrigated orchards. These facts are of wide significance as showing that irrigation may be found of benefit even where clean culture may not be thought desirable. It is certainly reasonable that if a cover crop is grown at all it should be attended by the surety that the trees shall not suffer for moisture, and they unquestionably do sometimes suffer seriously under old turf, even in lands of summer rains.

This view is wholly apart from the subject of exhaustion of soil fertility by intercropping. Of course, compensation for that depletion must be made by use of fertilizers, and whether the intercrop secured yields a profit upon such investment is a calculation foreign to this discussion. The purpose simply is to emphasize the fact that on rich soil ample irrigation can produce good fruit on an intercropped orchard, and it can do the same on a pastured orchard, but the height and form of a cow-pruned fruit tree is totally abhorent to present ideals.

A cover crop and an intercrop are, however, somewhat different things. The growth of a cultivated crop between the rows of fruit trees is permissible if the land is rich, and moisture, either by rainfall or by irrigation, is ample; but experience has shown that such a crop is only profitable while the trees are very young. As the trees expand they repress the growth of the intercrop below the profit mark, and give no further inducement to the grower to longer endanger the future of his trees by dividing their sustenance with the intercrop. On the other hand, a cover crop, if it be a legume, may reenforce the humus in the soil. One of the objections to continuous clean culture in the arid region is the tendency of the soil to lose humus and to become lifeless and refractory. The growth of clovers, peas, and other hardy legumes during the winter season, when the moisture is usually abundant, is being widely resorted to for the purpose of restoring humus. The

summer growth of tender legumes with ample irrigation is therefore, for this reason, as well as for lowering the soil temperature and escaping other effects of excessive temperature, worthy of consideration if water is ample enough to support the cover crop and the trees.

Clearly where such practice is advisable the irrigation method must be suitable. If the land is nearly level, low check levees on contour lines will restrain sufficient water and not interfere with the use of the mower. Such contour checks may inclose a considerable number of trees. With greater slope the square check system inclosing a single tree may be necessary, or flooding down the spaces between the trees, with a low levee along each row, may be the most available system. except in small orchards where pipe lines, hydrants, and sprinkling may be used.

MINOR RESULTS OF IRRIGATION:

It is obviously impossible to include in this general sketch many of the minor results of irrigation which have been demonstrated by half a century of experience in the arid regions, but a few may be noted:

In parts of California light frosts are likely to occur while citrus fruits are ripening and after the deciduous fruits have bloomed and set their fruit. This is from December to May. There is no hard freezing, but even a slight drop below the freezing point may occasion considerable loss of fruit. It has been found that over ground with a wet surface fruit may escape injury while that near by over a dry surface may be destroyed. For this reason irrigation water is used to prevent frost, and it has been found effective even when the mercury falls to 27° F., providing this temperature covers only a brief interval. If the mercury falls lower or remains too long at the point named, injury will result in spite of the presence of water, unless more effective methods of protection are resorted to.

To a measurable extent irrigation is found to hasten fruit ripening. In some cases several days have been gained with early varieties by giving water just as the fruit was getting good size. The same varieties near at hand proceeded more slowly without this stimulus.

The application of cold water to the roots of growing plants is very undesirable. Nearly all water derived from subterranean sources is improved by exposure to the sun, either by standing for a time in a shallow reservoir or traveling some distance in a shallow stream. Exposure to sun heat can not make the water too warm.

Irrigation performs a host of small services. In the nursery the budding season is lengthened because a run of water will cause the bark to slip later in the season. In the English walnut orchard the nuts will be more readily discharged from the husks if an irrigation is given a little in advance of the dropping time. Within certain limits fruiting can be timed by irrigation and succession secured. This is especially true of small fruits. Strawberries can be made almost con-

great bearers in suitable thermal situations and can have two main crops in the summer even where the winters are too cold for fruiting. Raspberries follow the same course, and ever-bearing blackberries are the ruling varieties in the warmer parts of the irrigated region. Of course these performances of plants are dependent upon temperature conditions as well as moisture conditions, and upon the length of the growing season which the irrigated semitropical region enjoys; but the fact remains that the forcing summer heat of the more northerly regions of the country could accomplish far more for the grower if by forethought and wise provision he should arrange to have that beneficence always attended by ample moisture. This is evidently one of the great works of the future.

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Rise and Future of Irrigation in the United States.

BY

ELWOOD MEAD,

Expert in Charge of Irrigation Investigations, Office of Experiment Stations.

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RISE AND FUTURE OF IRRIGATION IN THE UNITED STATES.

By Elwood Mead,

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REMAINS OF ANCIENT IRRIGATION WORKS.

The earliest pathway of civilization on the American continent led along the banks of the streams. In various parts of the Southwest, notably in the Salt River Valley of Arizona, in northern New Mexico, and along the southern borders of Colorado and Utah are well-defined remains of irrigation works which have outlived by many centuries the civilization to which they belonged. In at least one instance the bank of an ancient canal has been utilized as a part of modern works.

Riding up the valley of the Rio Grande, in the first half of the sixteenth century, Spanish explorers found in the midst of arid surroundings beds of beautiful roses, "not unlike those in the gardens of Castile," as they noted in their diaries. They also found Pueblo Indians irrigating the thirsty soil, as their forefathers had done for centuries before them and as their descendants are still doing to-day. In this valley and along the tributary streams, and at other places in the desert wastes of the Southwest, Spanish settlements sprung up and maintained themselves by means of these life-giving waters. The ditches at Lascruces, N. Mex., have an unbroken record of three hundred years of service, the history of which is written in the banks of the canals and in the fields irrigated. This is due to the sediment with which the waters of the Rio Grande are laden. Year after year this has slowly added layer on layer to the sides and bottoms of these ditches, until from being channels cut below the surface of the soil they are now raised 2 or 3 feet above. It is here that one can yet find agriculture almost as primitive as that of the days of Pharaoh, where grain is reaped with the sickle and thrashed by the trampling of goats.

EARLY IRRIGATION IN CALIFORNIA.

From these settlements and from the conquered cities of Mexico adventurous missionaries pushed their way still farther westward until they came in sight of the Pacific, teaching the Indians the crude art of irrigation, which they had learned either in Spain or of the simple inhabitants of the interior, and making oases of bloom and fruitage among the hills and deserts of the coast. So came the early

churches and gardens of California and the first small impulse toward the conquest of its fertile soil, which must always be gratefully associated with the memory of the Mission fathers.

Measured by their cost or the skill required to construct them, the small, rude furrows which watered these gardens are now of little importance. Compared to the monumental engineering works which have succeeded them, they possess to-day but little interest. The best preserved of these Mission gardens is now an insignificant feature in a landscape which includes miles on miles of cement-lined aqueducts, scores of pumping stations, and acres on acres of orange and lemon orchards, cultivated with thoroughness and skill not surpassed in any section of the Old World or the New. It was far different at the end of the eighteenth century, when the thirty or more of these gardens which were scattered along the coast between the Mexican border and San Francisco were the sole resting places of weary travelers and their fruit and foliage the only relief in summer from the monotonous landscape presented by the brown and arid hills which surrounded them on every side. They were under those conditions not only successful centers of influence from which to carry on the Christianizing of the Indian tribes, but forces tending to break up the migratory impulse by the establishing of homes among the early Spanish explorers.

BEGINNINGS OF MODERN IRRIGATION.

For the beginnings of Anglo-Saxon irrigation in this country we must go to the Salt Lake Valley of Utah, where, in July, 1849, the Mormon pioneers turned the clear waters of City Creek upon the sun-baked and alkaline soil in order that they might plant the very last of their stock of potatoes in the hope of bringing forth a crop to save the little company from starvation.

Utah is interesting not merely because it is the cradle of our modern irrigation industry, but even more so as showing how important are organizations and public control in the diversion and use of rivers. Throughout the pioneer period of their history the settlers of Utah were under the direction of exceptionally able and resourceful leaders, who were aided by the fact that their followers were knit together by a dominating religious impulse. These leaders had the wisdom to adapt their methods and shape their institutions to conform to the peculiar conditions and environment of a land strange and new to men of English speech. They found that irrigation was necessary to their existence in the home that they had chosen, and that the irrigation canal must therefore be the basis of their industrial organization, which was largely cooperative; hence, the size of their farms, which are less than 30 acres upon the average, the nature of their social relations, which are close and neighborly. (Pls. LIV and LV show some methods of irrigation and the improvement following the irrigation canal.)

FIG. 1. THE FIRST IRRIGATION.

FIG. 2. A LATER IRRIGATION.

FIG. 1.—APPEARANCE OF IRRIGATION CANAL WHEN FIRST COMPLETED.

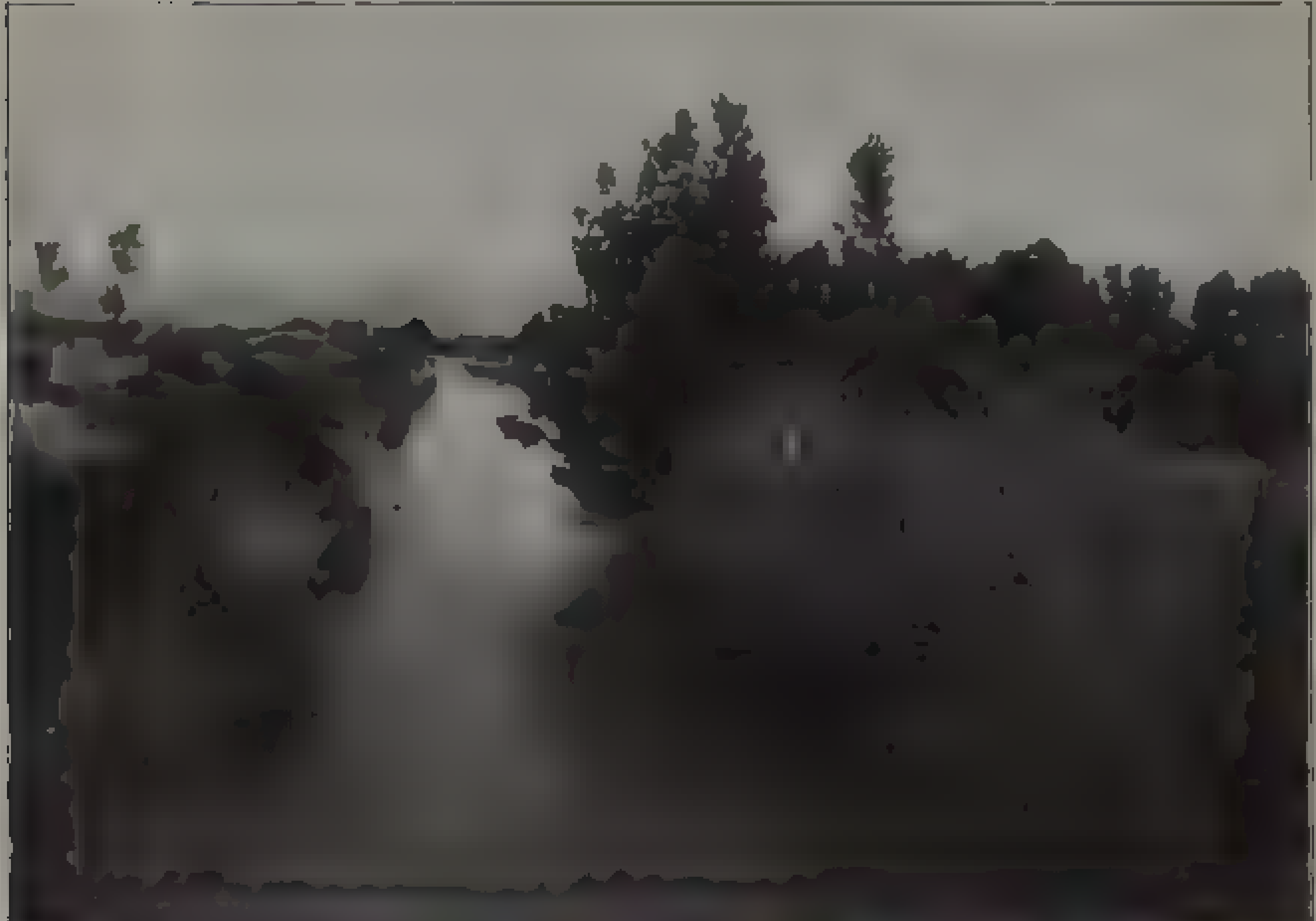

FIG. 2.—APPEARANCE OF IRRIGATION CANAL TEN YEARS AFTER COMPLETION.

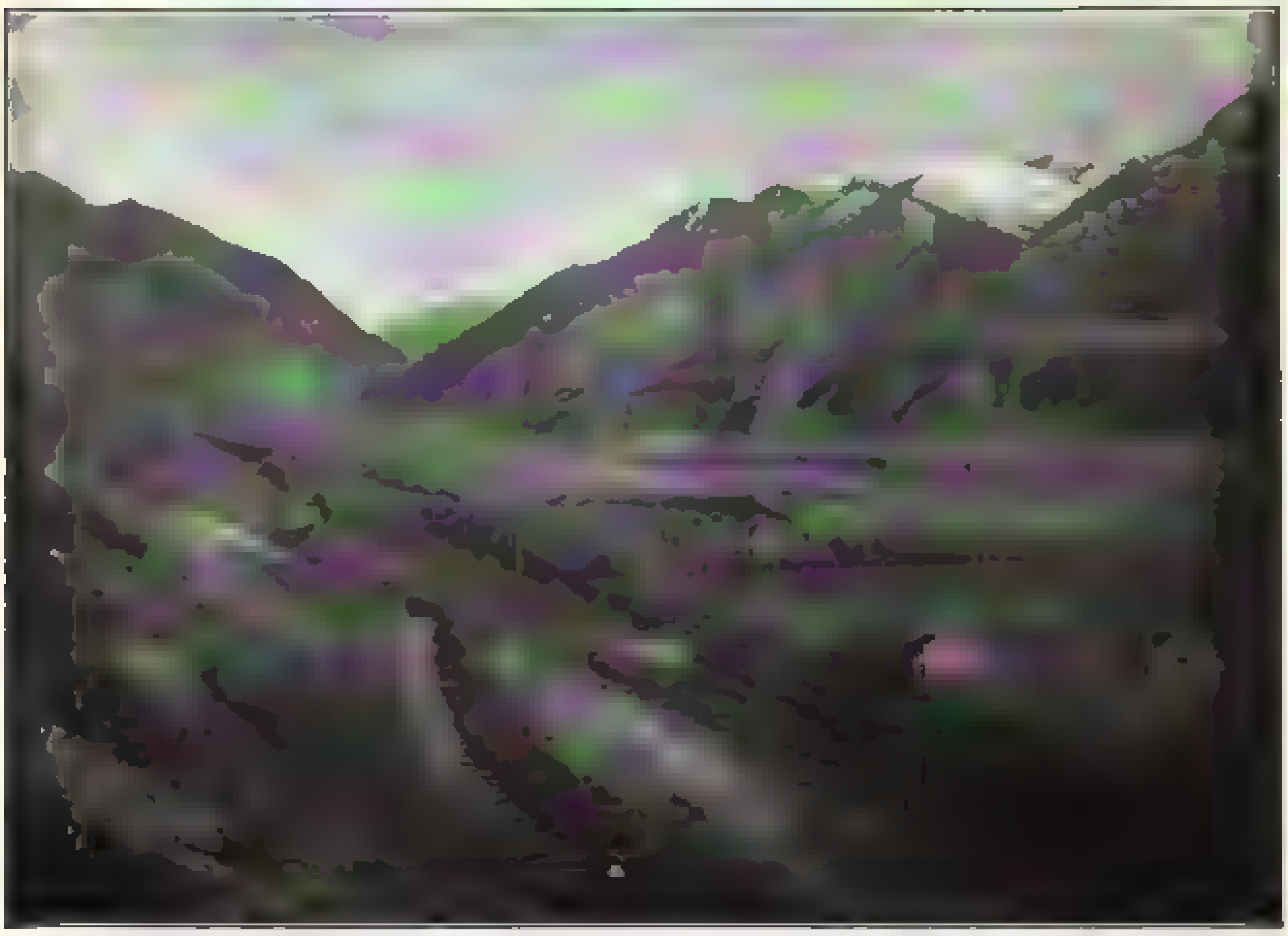

FIG. 1.—VIEW AT THE HEAD OF ONE OF THE EARLY IRRIGATION CANALS IN UTAH.

FIG. 2.—MOUNT UNION, FROM UNION PASS.

That the great material results which quickly followed could have been realized without the cohesion which came from an association dominated by religious discipline and controlled by the superior intelligence of the head of the Mormon Church, is doubtful; but that the character of institutions in the valleys of Utah, both industrial and social, was chiefly due to the environments in which they were placed is beyond dispute. Cooperation became the dominant principle simply because the settlers were in a land without capital, and it was beyond the power of the individual to turn the mountain current from its course and spread it upon his lands. Only the labor of many individuals, working under organization and discipline, could make the canals or distribute the waters. A small farm unit was chosen, not because men were less greedy for land than in all other new countries, but because it was quickly seen that the extent of the water supply was the measure of production, and their ability to provide this was small. Diversified farming, which is one of the leading causes of the remarkably even prosperity of Mormon agriculture, was resorted to because the Territory was so far removed from other settlements that it was compelled to become absolutely self-sustaining. The small farm unit made near neighbors, and this advantage was still more enhanced by assembling the farmers' homes in convenient village centers. One reason for adopting this plan, in the first place, was doubtless for protection against the Indians, but it has become a permanent feature, which is still adhered to in making new settlements because most satisfactory to the social instinct. (A view at the head of one of the early irrigation canals in Utah is shown in Pl. LVI, fig. 1.)

COOPERATIVE COLONIES IN COLORADO AND CALIFORNIA.

The discovery of gold in California created the Overland Trail, which wound its tortuous course across the hitherto trackless wastes of the arid domain. Its stations were usually along the banks of the streams. In the neighborhood of these, settlers had established themselves, and by means of simple furrows turned the waters of the streams upon the bottom land. This was the extent of irrigation throughout the vast region it traversed, outside of Utah, before the Union Colony at Greeley, Colo., became the second historic instance of the beginnings of the present system, and one which furnished a different standpoint for a study of the subject.

As Utah is the result of a religious emigration, so Greeley is the creation of the town meeting. Its founding marked the beginning of a new and different industrial development in Colorado. Before this it was the wealth of the mines or the migratory and adventurous experiences of the range live-stock business which had attracted settlement. Greeley, on the contrary, represented an effort of home-making people, both to enjoy landed independence and social and intellectual privileges equal to those of the towns and cities they had

left. Among its first buildings was Colony Hall, and among its first organizations the Lyceum, in which all the affairs of the community were debated with a fervor and fearlessness quite worthy of Horace Greeley's following. Cooperation was adopted in the construction and management of public utilities, of which the irrigation canal was the first and most important. The wisdom and justice of making common property of the town site, the beauty and value of which could only be created by the enterprise and public spirit of all, was recognized and put into practice with satisfactory results. The only deliberate extravagance was the erection at an early day of a school building worthy of the oldest and richest New England community. The highest methods both of irrigation and cultivation were sought out through numberless experiments, until Greeley and its potatoes grew famous together. The home and civic institutions of the colony became the pride of the State, and the hard-won success of the community inspired numerous similar undertakings and furnished an impulse which resulted in the reclamation and settlement of northern Colorado. Boulder, Longmont, Loveland, and Fort Collins were the outgrowth of success at Greeley, and each adopted many of the ideas and tendencies of the parent colony.

Twenty years subsequent to the beginning of Utah, and contemporaneously with the settlement of Colorado, similar influences began to make themselves felt in California, especially in its southern part. Anaheim is called the mother colony. This was cooperative in its inception, and its principal irrigation system has ever remained such. Riverside followed a few years later and represented a higher ideal; but the spirit of speculation in which California civilization was born soon fastened itself upon irrigation, as it had done in the case of mining, and ran a mad race through southern California. Irrigation in this State became corporate and speculative. Where Utah and Colorado had depended only upon their hands and teams for the building of irrigation works, California issued stocks and bonds, and so mortgaged its future. Men began to dream of a new race of millionaires, created by making merchandise of the melting snows, by selling "rights" to the "renting" of water, and collecting annual toll from a new class of society, to be known as "water tenants."

CORPORATE CANAL BUILDING.

The investment of corporate capital in canals to distribute and control water used in irrigation began in California, but spread like a contagion throughout the West. For a quarter of a century it has been the leading factor in promoting agricultural growth of the western two-fifths of the United States. It has been the agency through which many millions of dollars have been raised and expended, hundreds of miles of canals constructed, and hundreds of thousands of acres of land reclaimed. It has built the largest overfall dam ever

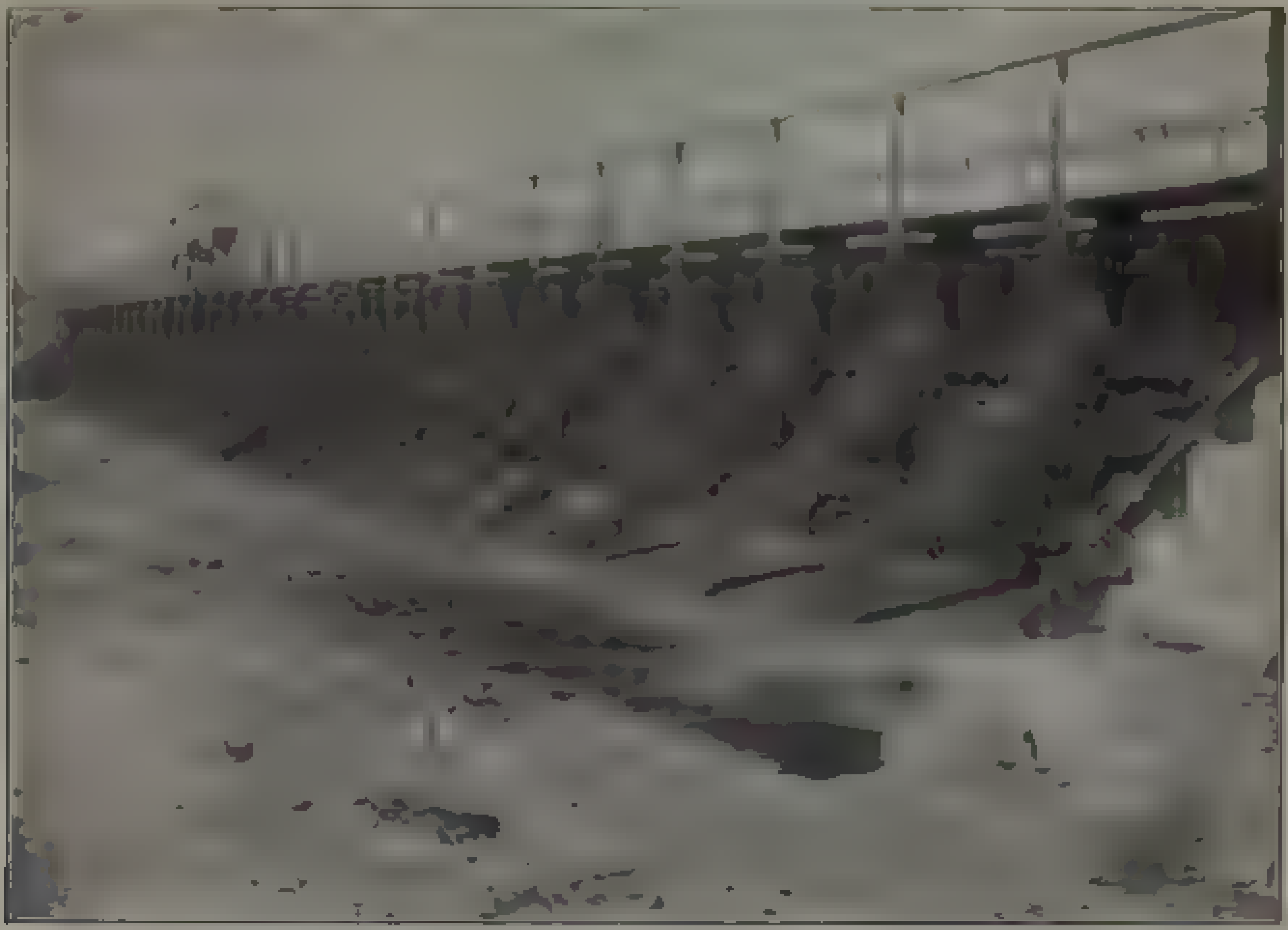

FIG. 1. CANAL WASTE GATE CLOSED.

FIG. 2.—CANAL WASTE GATE OPEN.

placed in a large river. It has been the chief agency in replacing temporary wooden structures by massive headworks of steel and masonry, and has, by the employment of the highest engineering talent available and the introduction of better methods of construction, promoted the economy and success with which water is now distributed and used. The question which is now to be considered is how the vast fabric created through its agency is to be directed and controlled in order that it may not crumble of its own weight. (Pl. LVII.)

The construction of irrigation works by corporate capital came as a natural if not inevitable evolution. There came a time in the districts first settled when the opportunities to divert water cheaply had largely been utilized, and when the expenditure required was beyond the means of either the individual or the cooperation of many individuals. The preliminary outlay was too great. In older European countries experience has shown that no agency can be so wisely intrusted with these larger expenditures as the State. Large irrigation canals have been considered as being, in their nature, as much public improvements as are works to supply water to cities and towns. Being for the service of the public, those in older European countries have largely passed under public ownership.

In this country corporations have, so far as construction is concerned, taken the place of governmental agencies in other lands. Practically all of the larger and costlier works built within the last two decades have been of this character. The High Line Canal, which waters the land surrounding Denver, Colo., with its tunnel through the mountains and its aqueduct carried along the rocky cliffs below; the canals of the Wyoming Development Company, with its tunnel alone costing more than all the Greeley Colony canals combined, and its reservoir for storing the entire year's discharge of the Laramie River; the Sunnyside Canal of Washington, which when built traversed 60 miles of sagebrush solitude, are illustrations in three States of the nature of corporate contributions to irrigation development. Even in Utah, cooperation was not sufficient to reclaim all of Salt Lake Valley. For forty years the table-land north of the lake, one of the largest and best tracts of irrigable land in the valley, remained unoccupied, while the sons of the pioneers were compelled to seek homes in the surrounding States. To reclaim this land, a canal had to be carried for 3 miles along the precipitous sides of Bear River Canyon. The flow of the river had to be controlled by an extensive dam and the Malad River twice bridged by long and high aqueducts, and the million-dollar outlay required was more than home seekers could provide.

The creation of water-right complications came with the building of corporate canals. Previous to this it had been the rule for those who built ditches to own the land they watered, and there was little

difference as to whether the right to water went with the ditch or with the land, because the ownership of both was united in the same person. But when companies were organized to distribute water for others to irrigate with and to derive a revenue from water rentals, there arose the question as to who was the owner of the right to the water diverted—the company transporting the water or the farmer who used it. The laws of nearly all the Western States make the ditch owner the appropriator. This has created a divided ownership of land and water, and many canal companies have framed water-right contracts on the theory of absolute ownership. These have proven a source of constant irritation to farmers. Some of these contracts require the farmer to pay, at the outset, a royalty or bonus for the "right" to receive water, the charge for this right varying from $5 to $500 per acre, depending on the scarcity of the water supply or the value of land and its products. There is a very prevalent feeling among farmers that as they are the actual "beneficial users" of the stream, they should be considered the appropriators, or at least that the owner of the land should share with the owner of the ditch in the right to water.

OBJECTIONS TO CORPORATE CANALS.

Having dealt with the benefits derived from corporate investments in irrigation works, it is now proper to point out their defects. The most serious one is that nearly all large canals have been losing investments. The record of these losses is so stupendous that it is reluctantly referred to. A single enterprise in one of the Territories represents to its projectors a loss of over $2,000,000. The Bear River Canal, in Utah, which cost over a million dollars, was recently sold under a judgment for about one-tenth of this sum. A single canal in California represents a loss to its builders of over $800,000. These are not isolated cases. Similar instances might be multiplied indefinitely. They are not due to bad management, to dishonesty, or faulty engineering. Some of the worst failures in a financial sense have been handled by the brightest and most experienced men in the West, but they were not able to make their enterprises pay, that is, they have not paid their builders. Nearly all have been a success so far as the section interested was concerned, but the benefits have gone to the public and not to the investors. The reasons for this should be more generally understood. The following are the most important:

(1) The necessarily long delay in securing settlers for the land to be irrigated, and in obtaining paying customers for the water to be furnished.

(2) The large outlay and several years of unprofitable labor required, as a rule, to put new land in condition for cultivation. Settlers of [illegible] means cannot meet this outlay and in addition pay water rentals, [illegible] of the settlers on arid public land are men of

limited means; hence, canal companies have at the outset to furnish water at small cost, or furnish to a small number of consumers.

(3) The unsuitability of the public-land laws to irrigation development.

(4) The acquirement of the lands to be reclaimed, in many instances, before canals are completed by nonresident or speculative holders, who would do nothing for their improvement.

(5) Expenses of litigation. Experience has shown that in the estimates of cost of a large canal provision should be made for a large and long-continued outlay for litigation. It begins with the adjudication of the stream and is protracted through the controversies over water rights.

WATER-RIGHT PROBLEMS OF THE ARID REGIONS.

After this brief sketch of the beginnings of American irrigation, some of the lessons of which will be considered at a later point in this article, we may appropriately turn to the great arid region as a whole and the complex legal, economic, and social problems with which its agriculture will vex the future.

Mount Union (Pl. LVI, fig. 2) rises in solemn grandeur in the Wind River Mountains of Wyoming south of Yellowstone Park. From this peak flow three streams, which, with their tributaries, control the industrial future of a region greater than any European country save Russia, and capable of supporting a larger population than now dwells east of the Mississippi River. These streams are the Missouri, the Columbia, and the Colorado. The first waters the mountain valleys on the eastern slope of the Rockies and the semiarid region of the Great Plains; the second, the Pacific northwest, including part of Montana, all of Idaho, and the major portions of Oregon and Washington; the third, the Southwest, embracing much of Utah and western Colorado, parts of New Mexico and California, and all of Arizona.

In this vast district, when reclaimed, homes may be made for many millions of people. To effect this result is a task inferior to no other in the realm of statesmanship or social economics. It is the nation's farm. It contains practically all that is left of the public domain, and is the chief hope of a free home for those who dream of enjoying landed independence, but who have but little besides industry and self-denial with which to secure it. As it is now, this land has but little value. In many places a township would not support a settler and his family, and a section of land does not yield enough to keep a light-footed and laborious sheep from starving to death. This is not because the land lacks fertility, but because it lacks moisture. Where rivers have been turned from their course, the products which have resulted equal in excellence and amount those of the most favored district of ample rainfall.

There are only 6,000,000 acres of cultivated land along the Nile. It is all irrigated. Where there is no irrigation there is desert. This little patch of ground has made Egypt a landmark in the world's history. It supports over 5,000,000 people and pays the interest on a national debt half as large as our own. The Missouri and its tributaries can be made to irrigate three times the land now cultivated along the Nile.

The essence of the problem to be met at the outset is the control and distribution of the water supply, since not only the enduring prosperity but the very existence of the homes created will be conditioned upon the ability to use these rivers for irrigation. The diverse interest of individuals and communities, and even of different States, will all be dependent on streams flowing from a common source. To reclaim all the land possible will involve the spreading of water over a surface as large as New England with New York added. Standing now at the birth of things and looking down the vista of the future, we can see in the course of these rivers the dim outline of a mighty civilization, blest with peace and crowned with a remarkable degree of prosperity, in case wise laws and just policies shall prevail in the years of the immediate future while institutions are forming. But if it be otherwise, if greed and ignorance are allowed to govern, and we ignore the experience of older countries than ours, there will remain to us only a gloomy forecast of legal, economic, and, possibly, even civil strife.

THE APPEARANCE AND RESOURCES OF THE ARID REGION.

In discussing this phase of the subject, let us follow the Missouri, Columbia, and Colorado rivers in their lonesome courses through mountains, plain, and desert to the place where one joins the Mississippi, where another mingles its waters with the Pacific, and where a third flows into the Gulf of California. For it is not only interesting but important to see in the midst of what surroundings so large a future population must dwell, and upon what other resources than water and land it will rear its economic edifice.

The climate of the western half of the United States takes its chief characteristic from its aridity, or dryness. The heat of its Southern summers and the cold of its Northern winters are alike tempered and mitigated by lack of humidity. Neither the humid heat which prostrates nor the humid cold which penetrates to the marrow is known in the arid region. The Western mountains and valleys are a recognized natural sanitarium where thousands of invalids are sent each year by physicians to regain their health.

The dominant feature in the physical appearance of the arid regions is its mountain topography. On every hand a rugged horizon meets the view. From North to South, from Canada to Mexico, the Rocky Mountain Range makes the backbone of the continent. Along the

Pacific coast the Sierra Nevada and Cascade ranges lift their barriers to intercept the moisture and condense it into snow. Between these two principal chains, with their connecting ranges and outlying spurs, are many minor systems, so that the whole country is a succession of mountains and valleys, of forests and deserts, of raging torrents and sinuous rivers winding to their sinks upon the plains or making their difficult way to the distant ocean. The far West is thus a land of the greatest scenic beauties, and widely celebrated as such.

The cultivable lands lie in the valleys, rising with gradual slope on either side of the streams to meet the foothills. Narrowing to the mountains, these valleys widen as the river loses grade and approaches the sea or its confluence with a larger stream. There are valleys which will accommodate hundreds, others, thousands or tens of thousands, and a few, like the Sacramento, in California, where millions may dwell.

In the eastern portion of the arid region, and in high altitudes farther west, the land is covered with nutritious natural grasses, which furnish ideal range for live stock. But the characteristic badge of the region is the sagebrush. This brave plant of the desert is commonly held in derision by those who behold it for the first time, and until they learn to know it as the shelter and dependence of range live stock when the terrible blizzard sweeps from the north and as the sure indication of good soil and the humble prophet of the field, orchard, and garden. Thus, it happens that to the casual traveler the appearance of the region is forbidding. It is only in localities where the work of reclamation has been in progress long enough to permit the growth of trees, with farms and homes, that the value of the soil and climate can be appreciated. There are such instances in all the seventeen States and Territories of the far West. One of the most striking is the Salt River Valley of Arizona. Here the traveler, after a long and tiresome journey through waste places, finds himself suddenly confronted with homes rivaling in taste and luxury those of Eastern States, and with orchards and gardens which resemble more the century-old gardens of France and Italy than a creation of the last twenty years.

Similar instances are the San Bernardino Valley of southern California, the Salt Lake Valley of Utah, and the Boise Valley of Idaho.

MINERAL WEALTH OF THE ARID REGION.

Another fact which contributes to the breadth of the economic foundation of Western agriculture is the variety and value of its mineral wealth. In this it is richly endowed, not only with the precious metals, but with the baser ones used in arts and industries, and with unusual quantities of coal, ore, and building stone, the latter of which includes many rare and valuable kinds, such as marble, onyx, and agate.

While the annual value of these products runs into the tens of millions of dollars, it is literally true that their development is yet in its infancy. With the extension of railroad facilities, the improvement and cheapening of mining processes, the extension of agriculture, and consequent increase in the volume and decrease in the cost of the home food supply, the gain in annual production will assume in the future dimensions which would now be considered beyond belief.

SOURCES OF FUTURE PERMANENT PROSPERITY IN THE ARID REGION.

To the mines must be added the forests which clothe the mountain sides, especially those of the northern part of this region. To a large extent this is still virgin ground, where only the foot of the hunter and explorer has trodden. It is a region unrivaled in its opportunities for the development of water power. The Shoshone Falls in Idaho are scarcely inferior to those of Niagara. The hundreds of streams which fall from the 10,000-foot level of the Rocky Mountain Range to the 4,000-foot to 5,000-foot level of the plain at their base are destined to turn more wheels of industry than have yet been harnessed west of the Mississippi River. Back of the irrigated lands are the grazing lands, of which there are probably not less than 400,000,000 acres. These lands have been the dominant factor of the pioneer life of many of the arid Commonwealths, and they are destined, under proper management, to always constitute the great nursery of cattle, sheep, and horses. The irrigated farm has back of it the mine, the furnace, and factory, and the civilization of Western America can not fail to have a prosperous and varied industrial life. Here there can be no one-sided development, no community exclusively devoted to the production of corn, wheat, or cotton, to manufactures, or to commerce. The farm, the stock ranch, the lumber camp, the mine, the factory, and the store are destined to grow up and flourish side by side, each drawing support from and furnishing sustenance to the others.

PRESENT AND FUTURE OF IRRIGATION.

The present situation, the results secured, and the tasks ahead in securing a wise disposal of the arid lands and in preventing the rivers from becoming an instrument of monopoly and extortion, will now be considered.

We are met at the outset by an entire absence of definite information. We do not know, nor is there any ready means of determining, how many irrigation works have been built. In many States no provision is made for their record. In only two States is this record even measurably accurate or complete. There may be 75,000 completed ditches, or there may be double the number, but either as to their number or as to the number of acres of land reclaimed thereby there is only surmise and conjecture. This, however, is known, that

the highest priced and most productive farm lands on this continent are in the arid region; that the largest yield of nearly every staple crop has been obtained by the aid of irrigation; that not only has the growth of agriculture furnished a market for the factories of the East and supported the railroads which unite the two extremes of the country, but it is the chief resource of nearly every one of the arid States. Colorado leads all the States of the Union in her output of precious metals, but the value of the product of her farms is nearly double that of her mines.

In California it is the grain fields and orange orchards which support the majority of her industrial population and furnish the basis for her future material growth and prosperity. The beginnings of Utah were wholly agricultural, and without the irrigated farms the cities of that interior Commonwealth would as yet be only a dream. In a less striking degree the same condition prevails in Idaho, Wyoming, Montana, New Mexico, and Arizona. This is the situation, while irrigation is as yet in its infancy. The reclaimed areas, though making a large aggregate, look very insignificant relatively to the rest of the country when delineated upon a map of the arid region. The possibilities of reclamation have but begun to be realized, yet when every available drop of water shall have been applied to the soil the irrigated lands will constitute a comparatively small proportion of the entire country. The possibilities of irrigation are, however, to be measured not alone by the possible extent of the agricultural industry, but by the development of other resources which it will make feasible. The best and largest use of the grazing lands, the utilization of the forests, the development of mines and quarries, and the maintenance of railroads and commerce in the western half of the United States, all hinge upon the control and use of streams in connection with the fundamental industry of agriculture. Since irrigation is essential to agriculture in the arid States, the extent and character of its development must surely measure the superstructure to be built upon that foundation.

GROWTH OF IRRIGATION AND NEED OF BETTER LAWS.

Some of the beginnings of irrigation have been referred to. The details of its growth can not be dealt with. It has been crude in many ways. There has been no attempt to provide for the diversion of rivers according to some prearranged plan having for its object the selection of the best land and the largest use of the water supply. Instead, each appropriator of water has consulted simply his ability and inclination in the location of his head gate. There has been an almost complete failure to realize that the time was coming when on many streams the demand would exceed the supply, and that a stable water right would be as important as a valid land title. The laws passed for recording claims are, as a rule, so loosely drawn and

imperfect that they would be a source of amusement if the evil results of their operation were not so disastrous. More than half of the State laws provide for inaugurating a title to water by posting a notice on the banks of the stream. They have not aided the proposed appropriator, because the right to post other appropriations was unrestricted. They are of no use as a warning to others, because not one in ten thousand of the parties concerned ever see them. A search for these notices along the cottonwood borders of the Missouri and its tributaries would be the unending labor of a lifetime; hence, the requirement was and is ignored; it is another of the many influences tending to unsettle irrigators' just rights and bringing the attempts to frame laws for their protection into disrepute.

Looking over the field at the close of the century, we find that the United States stands practically alone among irrigation countries in having left all the work of reclamation to the unaided efforts of private capital, and in the prodigality of the surrender of public control of streams. In one respect the policy pursued has been successful. It has resulted in an enormous investment (not less than $100,000,000, and some estimates make it twice that sum) and the creation of taxable and productive wealth of many times the amount invested. We have now about reached the limit of this sort of growth. There will be few large private investments in canals hereafter until we have better and more liberal irrigation laws. Entrance on the coming century is confronted by larger problems; the storage of flood waters, the interstate division of streams, and the inauguration of an adequate system of public control, which will insure to the humblest handler of a shovel his share of the snows falling on mountains above his farm, no matter how far removed therefrom he may be.

NEED OF REFORM IN THE MANAGEMENT OF ARID PUBLIC LAND.

Along with better water laws should come a corresponding reform in the management of the remaining arid public land. At the outset of its settlement these problems were entirely new to English-speaking men.

Early settlers came from the humid portions of Europe and settled along the humid coast line of the Atlantic and, later, in the humid valleys of the Ohio and Mississippi rivers. The land laws which they applied to the public domain of their day produced excellent results, making homes for millions of people and effecting a wonderful development of material resources.

When settlement had proceeded under these laws to the Missouri River and beyond, it was not strange that their principles were extended to the remaining public domain, for the vast majority of the American people had no conception whatever of the conditions existing in the far West. Not only the national lawmakers, drawn mostly from regions of abundant rainfall, but the legislators in the arid States

themselves were blind to the necessities of the situation. The value of gold they knew, but the value of that other element of national wealth, which will continue to sustain vast populations long after the last ounce of gold shall have been taken from the mine, they did not even dimly appreciate. So, to a large extent, they merely reenacted upon their statute books the common law of rainy and foggy England.

HOMESTEAD LAW NOT ADAPTED TO THE ARID REGION.

The homestead law may have served a useful, even a beneficent, purpose throughout large sections of the Republic, but it is not adapted to the settlement of a region where practically nothing can be grown except by artificial application of water. This fact has been learned at last through many years of hardship and disappointment, at the cost of many million dollars. One of the most pitiful pages in the history of the West is that which records the story of the settlement of the semiarid belt lying between the ninety-seventh meridian and the foothills of the Rocky Mountains. This is a territory 500 miles wide, extending from Canada to Mexico, including the western portions of the two Dakotas, Nebraska, Kansas, and Texas, and also eastern Colorado. In the absence of scientific demonstration to the contrary, tens of thousands of people rushed into this territory under the delusion that it was a land of reliable rainfall, or would soon become such as the result of settlement and cultivation.

New settlements sprung up in every direction, and important towns arose almost in a night. Men hastened from all parts of the country to claim their rights under the homestead law. Remembering the prosperity which similar armies of settlers had wrung from the virgin soil of the West, unlimited capital lent willing support to this new outward surge of growing population. The capital was largely lost, but the pathetic side of the picture was seen in the bitter disappointment of the settlers themselves. Many of them wasted the most useful and pregnant years of their lives in their brave persistence in the belief that the climate would change as the land came under cultivation, and that there was some magic potency in the homestead law to overcome the processes of nature. It is recognized at last that where water sufficient for purposes of irrigation can not be had the land is useful only for grazing. It is a mistake for the Government to offer to citizens land of that character on condition that they will settle upon 160 acres of it and make a living. There can be but one of two results—either the settler must fail or he must become practically the tenant of the person or corporation furnishing water for his dry land.

OPERATIONS OF THE DESERT-LAND LAW.

The desert-land law was devised to promote the investment of capital rather than to encourage settlement. For this reason it did not require actual residence on the land reclaimed. Originally, whoever

would irrigate 640 acres of land was given title thereto on the payment of the Government's price. Later this acreage has been reduced to one-half the original area. The operation of this law has been both useful and injurious. To give so large an area to men of small means is a mistake, because it is more than is needed to make a home and more than they can cultivate. It is not suited to corporate enterprise, or to reclaim large valleys which can be watered from a single canal, because it makes no provision for concerted or effective management of the entire area. Its field of effective usefulness has therefore been limited. While it has added somewhat to the taxable and productive wealth of Western States, it has also operated to transfer to single owners miles of water fronts which without this law would have been divided up into smaller farms with better social and agricultural conditions.

THE CAREY ACT.

What is popularly known as the Carey Act, from the name of its author, Senator Carey, gives to each State the right to segregate 1,000,000 acres of land and to control both its reclamation and disposal to settlers. The limitations of the operations of this act confine its benefits simply to the opportunity to secure better management during the time of canal building and settlement. Five States have accepted the trust, but in only one, Wyoming, have any canals been completed. These canals have been built by companies operating under a contract with the State. In Montana it is proposed to construct State canals from money obtained by selling bonds secured by the land to be irrigated. Enough progress has not as yet been made to determine whether or not this innovation on past irrigation methods is to meet with success; if it does, the third step in the evolution of canal building, which is the construction of State works, will have been inaugurated.

INFLUENCE OF THE RANGE INDUSTRIES.

To a certain extent there is an inevitable conflict between those who wish to use the public domain for homes and those who prefer to have it reserved for pasture, and, again, between those who wish to use the pasture for cattle and those who want it for sheep.

The range industries obtained possession of the field long before the higher utility of the lands for irrigation and settlement was generally appreciated. When irrigators did come, they worked more or less injury to the range stockmen, for each settler occupied a part of the water front and added to the number desiring to use the free grazing land. It is for the interest of the range-stock industry that access to streams be made as free as possible and that nothing be done to reduce their volume or prevent the overflow of natural meadows, while the higher interest of irrigation and settlement demands that the stream be diverted and its waters distributed over the widest

possible area. The conflict is between the wasteful use of water on the one hand and its economical use on the other, and, in a sense, between a primitive and a more highly organized civilization.

This statement should not be construed as denying that the range-stock industry is of vast importance nor that it will continue to be a great source of wealth to the country. Throughout the West there are very large areas suited to nothing else. The point is that the higher interest of society lies in the most economical and profitable use of water to the end that homes may be made for the largest possible number. Neither water nor land laws have favored this result, but precisely the contrary. The object of reform should be to preserve and develop all interests, to adapt laws and institutions to the peculiar conditions and environment of the region. This can be done with far greater security to the pastoral industries than they enjoy under the present system, and at the same time land and water available for making homes and farms utilized to the best advantage.

UNCERTAINTY AS TO STATE AND FEDERAL JURISDICTION.

The pioneers of irrigation are menaced by the uncertainty which exists as to the limits of State and federal jurisdiction in the control of streams. It has heretofore been assumed that the authority of each State within its borders was unquestioned, and two of the States contain constitutional provisions asserting absolute ownership and control of all the waters within their bounds. A recent decision of the United States circuit court in Montana holds this view to be erroneous, and that the snows which fall on public land and the streams which cross it are both under the control of Congress. A similar complication has arisen in litigation over a reservoir on the Rio Grande, in which both interstate and international rights are involved. In this case the United States Supreme Court has asserted the right of the General Government to protect the interests of navigation regardless of State statutes respecting the use of water in irrigation. The assertion of the paramount importance of riparian rights and of the protection of navigation, regardless of the use of water in irrigation, will add greatly to the uncertainty regarding water rights from the tributaries of the Missouri or any other of the rivers navigable in any portion of their course. The reclamation of the arid region involves the absorption of streams, and it can not be settled too soon whether or not such absorption is to be permitted.

COMPLICATIONS FROM LACK OF UNIFORM WATER LAWS.

On the other hand, serious complications have arisen from the absence of any general or national regulations governing the division of water across State lines. There are many instances where one stream is a common source of supply to irrigators in two or more States. It has sometimes happened that the perennial flow of such streams has been

first appropriated in a State along its lower course and utilized at a later period by other States near its source. Neither of the States concerned possesses power to remedy the evil, and each makes claim to all the water flowing upon its soil.

The conditions which govern irrigation throughout much of the arid region are practically uniform, and where this is true there is no question that a uniform irrigation law would operate with equal justice and efficiency; but, owing to the absence of such general supervision, water rights in States adjacent to each other are often as different in character as if these Commonwealths were on opposite sides of the globe. Failure to correct or regard these complications aggravates the evils to which they give rise and renders the ultimate adoption of a uniform system of laws far more difficult. There is but one thing the States have shared in common, and that is endless litigation over water rights. There is no uniformity of laws or decisions. The same issues are tried over and over again, and the precedent established in one case is overturned in another. The construction of costly works, and even the long use of water, has not always been sufficient to secure parties in their rights. Where rights have been successfully maintained, it has been done only at the price of constant lawsuits.

Usually the amount of water claimed is many times in excess of what the projected canal can utilize; frequently in excess of the entire volume of water in the stream. There is no one to protect the public interest as to the character of works to be built or to say whether they conform to good public policy. The courts confirm these loose appropriations, and the foundation for endless litigation is thus securely laid. The question soon arises as to who first appropriated the waters which do not suffice for all. There is then nothing to fall back upon except the faulty filings which were originally posted on the banks of the stream and the testimony of interested citizens. It frequently happens that old claims for very large amounts of water have not been utilized to their full extent until later comers have appropriated the unused surplus. The old claim is then enforced at the expense of the later one. The result is confusion, loss, and bitterness among neighbors.

The difficulty lies, first of all, in popular misconception regarding the nature of water rights and of property in water. This is enhanced by lack of scientific information concerning the character and extent of water supplies and of the amount required for beneficial irrigation Still further, there is a great need for a different system of appropri ating waters and of distributing a common supply among consumer These delicate and complex issues can not be fought out among pı vate parties without producing a condition of virtual anarchy, in whi the weak must go down and the strong survive, regardless of th merits or necessities. The failure of the irrigation industry from

financial standpoint is almost wholly due to the illogical land and water laws which have been described.

METHODS AND MEASURES NEEDED TO DEVELOP THE ARID REGION.

It is well to consider now by what methods and by what measures of legislation the splendid resources of the arid region may be opened to development.

The first step is to determine the proper control and just distribution of the water supply. The problem varies with different portions of the arid region. In the South, streams are generally torrential in character, furnishing the bulk of their waters in heavy floods, which must be stored in the many natural sites available in the mountains at a distance from the places where the water is to be applied to the soil. In the North, on the other hand, the problem is not that of storage, but of the diversion of great rivers like the Yellowstone, the Snake, the Columbia, and the Missouri. Here works adequate to the reclamation of the areas of arid land which remain can only be built at great cost, rivaling those along the Ganges and the Nile.

Before such development proceeds further it is desirable that some common agreement should be reached concerning the true character of water rights. The idea of private ownership in water apart from the land can not prevail without creating institutions essentially feudal in character. A water lord is even more undesirable than a landlord as the dominant element in society. It is indisputable, as has already been said, that the man who owns the water practically owns the land. A proposition which contemplates the turning over of all the land to a private monopoly, thus making a tenantry of those who may have their homes upon it in the future, could not hope to command popular support. But the idea of a private ownership of water, amounting to a virtual monopoly of this vital element, has been permitted to grow up in the West. To a certain extent it has obtained recognition in legislation and protection in judicial decrees and decisions. In other countries the doctrine has largely disappeared, and in our country it should give place to a more enlightened conception, and to the only principle that can safely be adopted as the foundation of the agricultural industry in the West.

The right to water which should be recognized in an arid land is the right of use, and even this must be restricted to beneficial and economical use in order that the water supply may serve the needs of the largest possible number. Ownership of water should be vested, not in companies or individuals, but in the land itself. When this principle is adopted, the control of the water is divided precisely like the land, among a multitude of proprietors. Reservoirs and canals are then like the streets of the town, serving a public purpose and permitting ready access to private property on every hand. Water monopoly is impossible under this method, and no other abuse is

encouraged by it. Years of painful experience have abundantly proven that peaceful and orderly development can not be realized except as water and land are forever united in one ownership and canals treated merely as public or semipublic utilities rather than as a means of fastening a monopoly upon the community. In Wyoming and Nebraska the true principle has already been adopted by the State boards of control and put into practice with the best results. If it can be maintained and speedily extended to the other States, as it surely must be in time, it would mark an economic reform of the highest significance in the life of the West.

APPROPRIATION AND DISTRIBUTION OF THE WATER SUPPLY.

Next in importance to the correct solution of the question of water ownership are the great problems of appropriation and of distribution. As soon as possible all ditches used in irrigation should be carefully measured by some public authority and the results of this measurement be given the widest publicity, in order that irrigators may know approximately how much is taken and how much remains to be taken by new canals. The need of this information is so obvious that it will perhaps be difficult for readers unfamiliar with the subject to credit the assertion that in all but four of the Western States the matter has been wholly neglected. This fact is largely responsible for the disheartening litigation which prevails so widely.

It is of almost equal importance to have a scientific determination of the practical duty of water, showing the amount required for different soils and crops. Still further, there must be some form of public control in the distribution of water. Trouble always results when this is left to rival users to determine how much they need, especially in years of partial drought, when the supply may be insufficient for all, and it is consequently necessary to recognize appropriations in the order of their priority.

(Check gates on main canal and a measuring weir are shown in Pl. LVIII.)

PUBLIC SUPERVISION AND CONTROL OF IRRIGATION.

The entire discussion leads up to one inevitable conclusion: This is that irrigation, over and above all other industries, is a matter demanding public supervision and control. Every drop of water entering the head gate, and every drop escaping at the end of the canal, is a matter of public concern. The public must determine, through constitutions and statutes, the nature of water ownership. The public must establish means for the measurement of streams and for ascertaining how much water may be taken for each acre of land under the principle of beneficial use. The public must see that justice is done in the distribution of water among those who have properly established their rightful claims to it. We have thoroughly tried the method of

FIG. 1.—A CHECK AND LATERAL GATE ON MAIN CANAL.

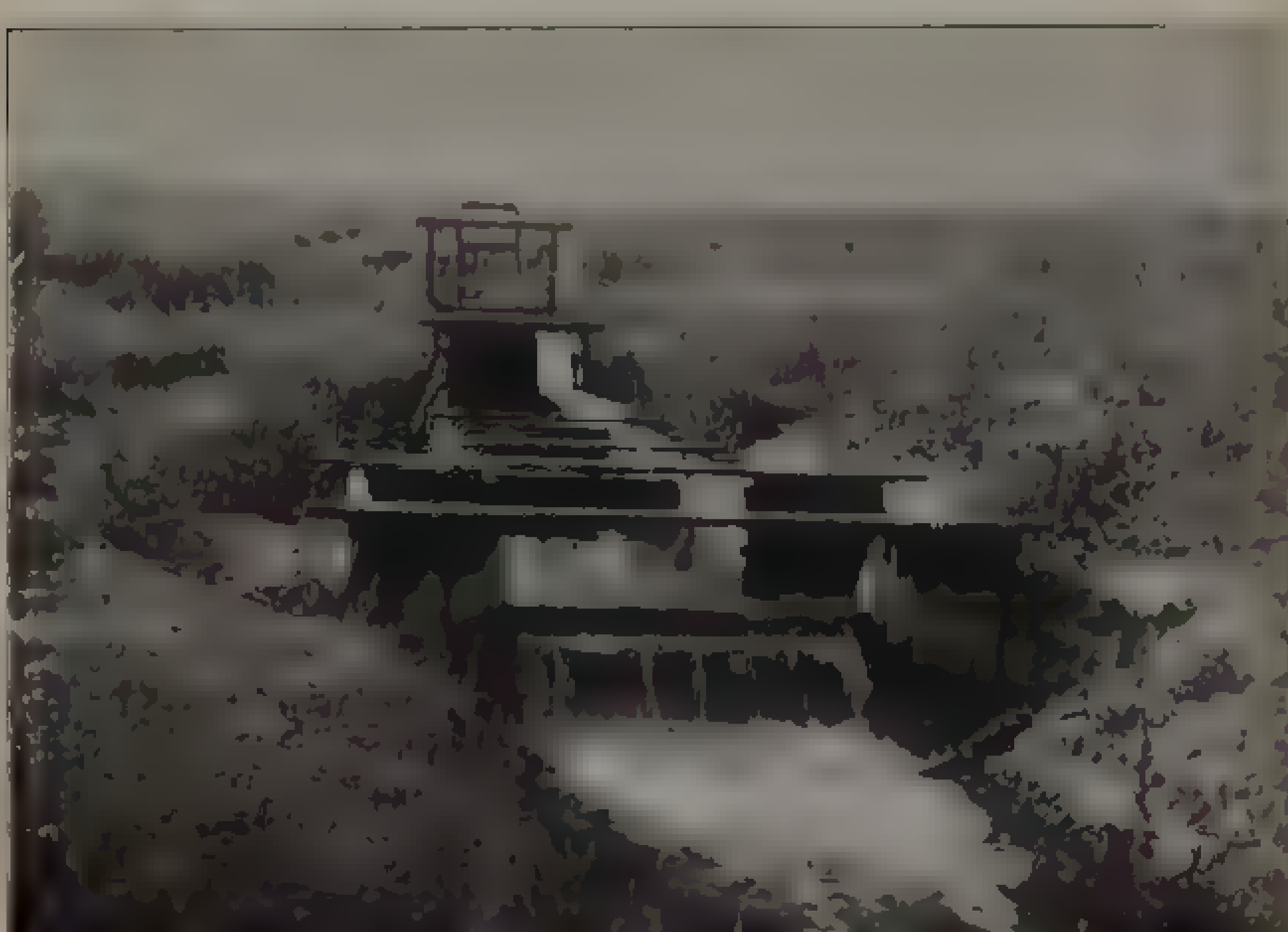

FIG. 2.—A CIPPOLETTI MEASURING WEIR.

leaving all this to private initiative and management, and, along with magnificent material progress, we have reaped a large crop of deplorable financial results.

While much must be left to the action of States and communities, there is still a wide field for national effort. Only the nation can legislate as to the public lands and reform the abuses which have been referred to in connection with the present system of land laws. There is a strong popular demand in the West for legislation providing public aid in the construction of works of too great magnitude and cost for private enterprise and a growing belief that one of two things should be done: Either the arid States should be placed in a position to extend this aid, or the General Government should extend the work it is now doing in the reclamation of certain Indian reservations to the reclamation of the unoccupied public lands. One policy much discussed and widely favored is legislation which will permit of the leasing of the public grazing lands for a term of years at a small annual rental, the proceeds to be given to the several arid States and applied by them to irrigation development. If this is carried out, the settlers owning the contiguous irrigated land should be favored; the object being to unite with the lands reclaimed a certain portion of the public pasture.

The National Government alone can make the best and broadest study of the various economic questions related to the development of agriculture on arid lands. This includes not only the measurement of streams and survey of reservoir sites, but also a consideration of practical methods of applying water to the soil and of social and industrial institutions adapted to the environment of the arid region. The nation alone can deal with the conflicting rights in interstate and international streams and with the construction of great reservoirs at their head waters, with a view to benefiting the several States lying along their course. The National Government is already active along all these lines, and the field for the expansion of its efforts is wide and inviting.

INFLUENCE OF IRRIGATION UPON PEOPLE AND COUNTRY.

While a description of existing conditions in the far West necessarily includes references to many evils and disappointments, there is a brighter side to the picture, and the future is luminous with new hopes for humanity. A vast population will make its homes in valleys now vacant and voiceless, yet potentially the best part of our national heritage. They will create institutions which will realize higher ideals of society than the world has yet seen. Irrigation is much more than an affair of ditches and acres. It not only makes civilization possible where men could not live without it, but it shapes that civilization after its own peculiar design. Its underlying influence is that which makes for democracy and individual independence.

IRRIGATION PRODUCTIVE OF SMALL PROPRIETORS.

Where land can only be cultivated by means of the artificial applition of water, and where that water is not under speculative control, it is owned in small holdings. This is so because irrigation intensifies the product of the land and so demands much labor. It is a kind of labor which can not profitably be left to hired hands. The result is a multitude of small proprietors working for themselves. This fact is strikingly illustrated in southern California. Here the farms are small and almost exclusively occupied by their owners. But the great wheat ranches in other parts of the State, notably in the Sacramento Valley, depend chiefly upon hired laborers, who make no homes of their own. The Sacramento Valley has less population now than it had twenty-five years ago. Of the increase of the rural population of the State between 1880 and 1890, 77 per cent went to the irrigated counties, and largely consisted of families who bought small farms and proceeded to do their own work. The influence of a great mass of small proprietors tilling their own land can not fail to have a very marked effect upon the character of the institutions.

DIVERSIFIED FARMING A FEATURE OF IRRIGATION.

Irrigation lends itself naturally to diversified farming and tends to make population self-sufficient within itself. Although in certain localities, especially those where the climate is favorable to raisins and oranges, the contrary has sometimes been true, the tendency of irrigation as a whole has been to discourage the production of single crops and make families independent by producing the variety of things they consume. This tendency is steadily gaining ground. The diversified farming which irrigation both permits and encourages will be an important element in contributing to the independence of the people who shall inhabit the arid region of the future.

IRRIGATION AS A TRAINING IN SELF-GOVERNMENT.

Another interesting feature of irrigation is the training it gives in self-government. A farmer under irrigation can not remain ignorant and indifferent of public questions. He has to consider his interest in the river which feeds his canal and the nature of his relation to other users along its course. It is a training school in self-government and gives the first impetus to civilization in rainless regions The capacity of the American farmer has already been demonstrated. He is the author of the best of our irrigation laws. Colorado was the first State to enact a law providing for the public control of streams and some sort of systematic procedure for the establishment of rights, but the credit of that is not due to her statesmen, but to the discussions of the Greeley Lyceum and the public spirit and independence of the irrigators under the Colony Canal. Opposed by the conservatism

of the legal profession and the prejudices of those not practically familiar with the subject, they had a long and doubtful struggle to secure the adoption of a statute which for a time made the State the lawgiver of the arid region.

In Utah the practices of water users are a hundred years in advance of the State laws. This is due to the fact that irrigators recognize insensibly the community nature of their interest in the streams. The old feudal idea of private ownership in water has never made an irrigated district prosperous, and it never will.

IRRIGATION AND COOPERATION.

Another feature is the tendency toward cooperation. Under the Wyoming law accepting the Carey grant this cooperation is made obligatory. Every settler under a canal becomes a shareholder therein. Not only does the right to water attach to the land, but a share in the canal sufficient to carry the water also goes with it. In fact, the need of watering many farms from a common source and of organizing a community under rules and discipline for the distribution of the supply make a nursery of cooperation. Its most conspicuous manifestation is in the widespread and successful fruit exchanges of California. There are many instances of smaller and more local organizations of a cooperative industrial character, and they are multiplying rapidly. They seem likely to deal with yet larger affairs in the future as communities gain in age, numbers, and wealth.

EFFECT OF IRRIGATION ON SOCIAL LIFE.

Heretofore one of the evils of the irrigated home has been its isolation. The valleys of many streams are narrow. The broad areas which lie between these valleys are the home of cattle and sheep, but not of men. The Anglo-Saxon thirst for land, and the opportunity which the desert-land act gave to gratify it, resulted at first in a wide separation between homes, and in a loss to the pioneer of the advantages of schools, churches, and social life. Under the larger and later canals the tendency has been in the other direction. The European custom of making homes in village centers has been adopted in parts of Utah, Wyoming, Idaho, and California, and steadily gains in public favor. Where farmers live in villages, their families enjoy ready access to schools, churches, libraries, and entertainments. The agricultural society of the future in the Western valleys will realize a happy combination of town and country life—the independence which springs from the proprietorship of the soil and the satisfaction of the social instinct which comes only with community association. Such conditions are favorable to the growth of the best forms of civilization and the noblest institutions. This is the hope which lies fallow in the arid valleys of the West. Its realization is well worth the

struggle which is impending for the reform of our land and water laws, and which will impose high demands upon our statesmanship and call for the exercise of the best order of patriotism.

THE COMMERCIAL IMPORTANCE OF IRRIGATION.

The commercial importance of the development of irrigation resources is being realized in the West at the present time as never before. Especially in California there is a new awakening, and an effort on the part of the best elements of citizenship to remove the obstacles which have formerly hampered both public and private enterprise. The East, as a whole, is beginning to realize the great part which the West is to have in the events of the twentieth century. World-wide forces are working to hasten the day of its complete development and of the utilization of all its rich resources. The Orient is awake and offering its markets to the trade of the Pacific coast. With the development of this trade there will come an impulse for the completion of the material conquest of arid America by the enlistment of public as well as private means in the storage and diversion of its streams for the irrigation of its hundred million acres of irrigable soil; the harnessing of its water powers to mill and factory wheels; the crowding of its pastures with new millions of live stock; the opening up of its mines and quarries; the conversion of its forests into human habitations; the coming of a vast population, and the growth of institutions worthy of the time and the place.

BULLETIN No. 36. 196

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS.

NOTES ON IRRIGATION

IN

CONNECTICUT AND NEW JERSEY.

BY

C. S. PHELPS, B. S., AND EDWARD B. VOORHEES, M. A.

WASHINGTON:
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1897.

LETTER OF TRANSMITTAL.

UNITED STATES DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., December 15, 1896.

SIR: I have the honor to transmit herewith, and recommend for publication as Bulletin No. 36 of this Office, two articles on irrigation in the Eastern United States, entitled, respectively, Irrigation in Connecticut, by C. S. Phelps, professor of agriculture, Storrs Agricultural College, and vice-director Connecticut Storrs Agricultural Experiment Station, and Irrigation in New Jersey, by Edward B. Voorhees, M. A., director of the New Jersey Agricultural Experiment stations and professor of agriculture in Rutgers College. These articles embody in part investigations conducted by the Connecticut Storrs and New Jersey Experiment stations.

Although irrigation has been practiced for many years in the Eastern States on a limited scale, especially on grass lands, it is only within a comparatively few years that any widespread interest has been manifested in the subject in this region.

In recent years, however, widespread drought, especially at critical periods in the life of certain crops, has drawn the attention of Eastern farmers and horticulturists to this subject, and there has been much discussion of the practicability of irrigation under humid and subhumid conditions. Truck farmers and fruit growers in regions accessible to good markets are beginning to appreciate the importance of irrigation, and there seems to be a demand for information on the practice as applied to Eastern conditions.

A popular discussion of the principles and practice of irrigation in humid climates was given in Farmers' Bulletin No. 46 of this Department. The present publication is intended to supplement this bulletin and to show the need and possibilities of irrigation in two representative Eastern States, the methods pursued and results obtained by those farmers who have undertaken to practice irrigation in these States, and the problems needing investigation.

In connection with the report on irrigation in New Jersey acknowledgment is due to Mr. C. C. Vermeule, author of Water Supply, Geological Survey of New Jersey, 1894, for important data concerning the water supply of the State accessible for irrigation, and the estimated cost of irrigation plants, and to Mr. George A. Mitchell, of Vineland, for much statistical matter in reference to a number of the irrigation plants now in operation in the State.

Respectfully,

A. C. TRUE,
Director.

Hon. J. STERLING MORTON,
Secretary of Agriculture.

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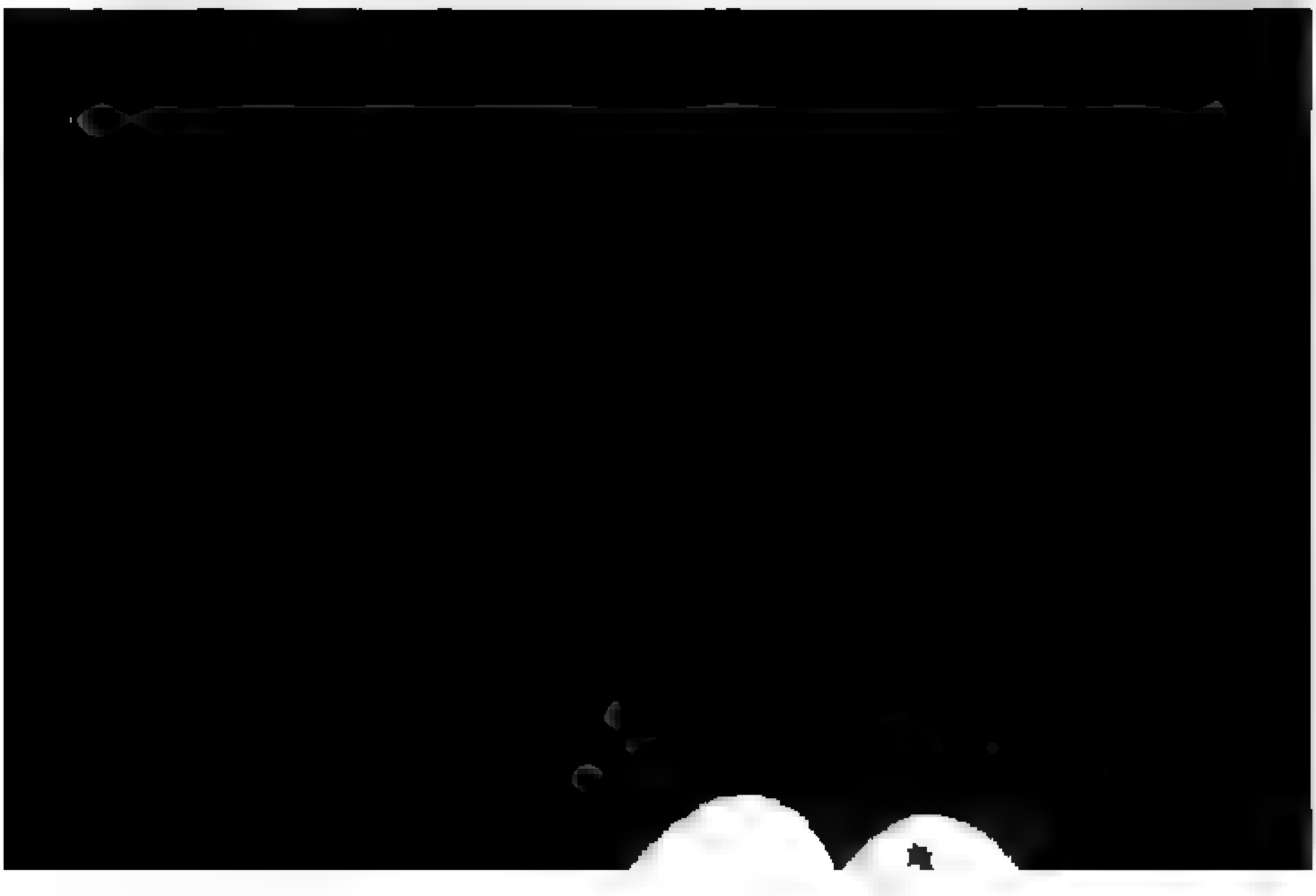

NOTES ON IRRIGATION IN CONNECTICUT AND NEW JERSEY.

IRRIGATION IN CONNECTICUT.

By C. S. PHELPS, B. S.,
Professor of Agriculture, Storrs Agricultural College, and Vice-Director, Connecticut Storrs Agricultural Experiment Station.

INTRODUCTION.

Up to the present time little has been done in the Eastern States in the use of irrigation either on farm, garden, or orchard crops, but its great value has been demonstrated in a few striking instances by some of our leading fruit growers, and these instances, together with the general interest that is being manifested in the subject, show the need of inquiry. Within the past few years there has been a lively agitation of the subject through the agricultural press of the East, and farmers and small fruit growers are beginning to appreciate the value of artificial watering, and an increasing demand seems to exist for all the information obtainable on the subject.

In the eastern portions of this country the intensive system of agriculture is rapidly replacing the extensive. This has become necessary because of the rapidly increasing population and a corresponding increase in the value of lands. In the past fifty years the agriculture of New England has been entirely changed. A system of general husbandry has been largely replaced by special branches of farming. The many thriving manufacturing cities and towns that have been built have caused a great demand for fruits and vegetables. These products have proven especially profitable where markets are near at hand. The high value per acre and the active and increasing demand for fresh fruits and vegetables have induced many of our farmers to enter upon the production of these crops, and it is in such lines of farming as fruit growing and market gardening that irrigation has its highest value. Where the cost of cultivation is large the losses from drought are felt all the more severely, as the expenses are essentially the same whether a half crop or a full crop is harvested. In the eastern part of this country droughts are not usually of long duration, but short, severe droughts are common, and they cause heavy losses to market gardeners and fruit growers. Losses of from $100 to $200 per acre as a

result of a few weeks' drought are not uncommon. The area devoted to strawberry culture during the season of 1895 in Connecticut is estimated at not less than 500 acres. With this total acreage a loss of $100 per acre means, for one small State, a loss of $50,000 on a single crop.

The experience of practical men and the experiments cited beyond indicate that an investment in an irrigation plant where market garden crops and small fruits are grown will pay exceptionally good interest.

NEED OF IRRIGATION IN CONNECTICUT.

The majority of people fail to realize that irrigation has any place in New England agriculture. The annual rainfall in this region is generally thought sufficient to meet the needs of most, if not all, of the farm crops grown, and that any considerable expenditure of money for irrigation would not repay the expense except in very exceptional cases. The rainfall, however, is very unevenly distributed throughout the year. Short, severe droughts are a characteristic of the climate. A high temperature, accompanied by drying winds, will in a week's time frequently cause the crops to wilt, and in less than two weeks the crop prospects may be nearly ruined.

A rainfall of 3 inches per month, if fairly well distributed throughout the month, would probably produce an average growth of most farm crops. With less than this amount of rainfall many crops fail to make a normal development. During the past eight years the Connecticut Storrs Experiment Station has made observations on rainfall during the growing season at about a dozen different places in the State, and from these and others made for the New England Meteorological Society are taken the following figures for the rainfall for the five summer months:

Rainfall in Connecticut during summer months, 1888 to 1895.

Year.	May.	June.	July.	August.	September.	Total five months.	Average per month.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1888	....	1.58	2.00	5.59	8.43	....	4.40
1889	3.75	3.53	11.35	3.92	4.67	27.22	5.44
1890	5.19	2.96	4.29	4.29	5.45	22.18	4.44
1891	1.82	2.47	4.24	3.81	3.31	15.65	3.13
1892	5.31	2.65	3.80	4.35	2.17	18.28	3.66
1893	6.99	2.65	2.12	4.69	2.69	19.14	3.83
1894	5.07	.75	1.55	1.81	4.15	13.33	2.67
1895	2.26	2.74	4.36	4.54	2.44	16.34	3.27

From this table it will be seen that the average rainfall has been below 3 inches for June seven years out of eight, for July three years, for August one year, and for September three years.

The rainfall for the growing season (May to September), were it evenly distributed through the different months, would usually prove sufficient for the needs of most crops. From the above table it will be seen that the rainfall for different months is very irregular. While the

water which accumulates in the soil during the portions of the year when vegetation is not growing may be of some benefit to crops, yet a large part of the water used, especially where the ground water is quite a distance below the surface, must come from the rain that falls while the crops are growing. A remarkable instance of the excess of rainfall which often occurs when crops need the water least, and a deficiency during those months when crops use water most largely, may be seen in the rainfall data at Storrs, Conn., for the year 1895. The five summer months from May 1 to September 30 showed a total rainfall of 14.5 inches, while the two succeeding months—October and November—gave a rainfall of 13.7 inches.

There are very few seasons during some part of which a drought of more or less severity does not occur. With crops like strawberries, raspberries, early potatoes, and onions, a lack of rain for two or three weeks may lessen the crop by one-half or more. A striking illustration of the injury caused by short droughts was seen during the season of 1895 on one of the farms of this State where irrigation was being put in operation for the first time. A field of strawberries that had been set out in the spring of 1894 was on too high ground to be reached by conducting the water from the storage pond, while a field of the same size on another part of the farm was sprinkled from pipes laid on the surface. The irrigated area, with only three applications of water, gave a yield two and two-thirds times greater than that obtained where no water could be applied.

Many Connecticut soils are of such a character that they suffer readily from drought. Some of the best soils for market garden and fruit crops are light and sandy with gravelly subsoils. These suffer readily from drought, but when supplied with sufficient water give large crops of the best quality.

A strong argument in favor of irrigation in Connecticut is found in the high value per acre of many farm and garden crops. The following table shows the range of value per acre for some small fruits and market garden crops grown on unirrigated soil, as given by practical farmers. These were chosen because they have proven especially valuable in the few instances where irrigation has been practiced in this State:

Value of different crops per acre.

Strawberries	$200 to $450
Raspberries	200 to 400
Asparagus	100 to 200
Cauliflower	200 to 400
Celery	200 to 300
Onions	150 to 300
Muskmelons	300

It will readily be seen that a loss of one-half on some of these crops when five or six acres are grown would cover quite an outlay for water. The two men in Connecticut who have made the most extensive use of

irrigation state that the cost of their irrigation plants was returned the first season by the increased crops obtained.

With crops like strawberries and raspberries the benefits derived from irrigation represent only a few weeks' labor and a small expenditure of money. So great is the gain derived from having an abundance of water for these crops at the right time that good profits have been obtained by the use of a road engine and force pump. In many places this form of power could be hired for a few days and large profits obtained from its use.

Before farming products were shipped long distances by rail, the prices obtained for the crop in any locality depended largely upon the supply in that immediate vicinity. If the season was not a favorable one for any particular crop and the yields were light, the increased price obtained often counterbalanced the deficiency in the yield, so that the weather conditions did not so largely regulate the profits. To-day, however, if in one locality there is a shortage in any crop that will bear long carriage, the markets may be stocked from places long distances away, where the weather conditions were perhaps favorable for large yields. The profits obtained by local growers are thus largely dependent upon the season.

METHODS OF IRRIGATION IN USE IN CONNECTICUT.

The sources of water for irrigating purposes in Connecticut are mainly from small natural streams, from ponds, and from springs. No instances are known to the writer of the use of water from wells for irrigating purposes in this State. The water is usually stored either in open ponds or in large tanks. The means of making the water available are through some form of power, such as a ram or windmill, or, when the source is high enough above the fields to be watered, it is conducted to and over the fields through open ditches or pipes. There are many instances in Connecticut where the water can be made available only by some form of power, as the water is below the fields upon which it is to be applied. There are two farms in the State where powerful rams have been very successfully used. Where the water is supplied by means of a ram or other pumping appliance it becomes necessary to economize in the use of water and to prevent losses by evaporation in order to reduce the expense. For these reasons it has been found more economical to apply the water from pipes distributed over the fields. The water is sometimes allowed to flow between the rows from pipes laid along one end of the field. In other cases it is applied by spraying. The cheapest and simplest method of distributing the water is by conducting through open ditches, and there are several instances where this is being successfully done.

HISTORY OF IRRIGATION IN CONNECTICUT.

There are a number of abandoned irrigation plants in Connecticut that were in operation forty years ago. One of these is located at

Salisbury, another at Torrington, and a third at Newtown. The one at Salisbury was owned and operated by Albert Moore. In 1866 he wrote regarding his use of irrigation:

I have raised enormous crops of corn without manure, and have had similar results with rye, oats, and potatoes. From a poor piece of land, yielding less than a ton of hay, white daisies, and large Saint John's-wort to the acre, I now get 3 tons of first-quality hay without plowing or seeding. The daisies and Saint John's-wort have entirely disappeared, and Canada thistles and other injurious plants do not attain a foothold on irrigated land. This I attribute to the very thick growth of grass, as I have counted from 8 to 12 grass plants on a square inch of irrigated turf, and not over one on the same area of unirrigated, but a few feet apart. Meadow moles and mice, grubs, and grasshoppers, and all other insects and vermin, cease their depredations on irrigated land.

All kinds of farm stock prefer the hay, and eat it with avidity, and do well on it. I have even known sheep to fatten on it alone in winter, and become fit for the butcher in the spring.

The meadow requires no other manure, and when the hay is consumed on the farm it contributes largely toward furnishing manure for other parts of the farm. Cattle eat the stems of the hay much cleaner than of other hay, as by growing so thick it is so much finer and less distasteful than hay from heavily manured land. I have frequently seen grass standing over 5 feet high, by measurement, on one side of an irrigating ditch, while on the opposite side, where the water could not reach, the grass was scarcely a foot high.

The irrigated portion of a large pasture is constantly fed down much closer and shorter than the adjacent portions, beyond the reach of the water. The grass on irrigated land not only starts earlier in the spring, but holds out later in the autumn, thus shortening the foddering season at both ends. The water tends effectually to keep off both early and late frosts. Even if a field of corn is flooded a few inches deep in a frosty night, it will escape the effects of the frost, and the same is true of tobacco and other like crops.

A small rill of water which flows but a month or two in the spring, if spread over the adjacent surface of grass, will, if continued yearly, soon show its good effects the entire season, and the effects of irrigation are often of the most reliable and durable nature.

I have never noticed any different effect from hard, soft, cold, or warm brook or spring waters. My theory is that all water contains fertility in solution, and by irrigation it is placed or even put into the mouths of the rootlets of plants and absorbed at once; that it is not so much the water itself as what it contains which causes the result.

I can point to large apple trees now standing and bearing well on a meadow irrigated profusely for the last fifty years. In another meadow young apple trees are doing well where the irrigation is applied both winter and summer.

The grape, currant, raspberry, Lawton blackberry, asparagus, tomatoes, spinach, horseradish, and other fruits and garden vegetables, which bring a high price in market, thrive well under irrigation, but it must be land naturally adapted to irrigation and not naturally wet.

The only ill effect which I have noticed is that the grass, if not cut when mature, is a little more liable to lodge or fall down, in which case the water should be withheld at once, and the grass cut without delay, and the water let on for a second crop.

In 1866 Hon. T. S. Gold, secretary of the State board of agriculture, wrote in regard to the work on irrigation done by Mr. Thrall, of Torrington, and Mr. Mitchell, of Newtown:

Mr. Thrall has upon his place a stream large enough to turn a mill; and for the last twenty years he has irrigated, by water from this stream, a field of from 4 to 6

acres of low, sandy land, and which has been made to produce abundantly. I have never observed manure to have been used upon this land. The expense is not excessive. He first erected a cheap wooden dam to collect water for the supply of his fields. About ten years ago he removed this wooden dam and put up a stone dam at an expense of more than $100, for the purpose of raising water to a sufficient height to make it flow through his little channels and over his fields. His crop, of course, is large and fine; and he is one of our practical farmers who evidently thinks that irrigation pays well.

Mr. Mitchell has some 50 or 60 acres of hungry, gravelly soil, on the banks of the Housatonic River, which were as valueless as you can find anywhere, not bearing decent mullein stalks. He had graded most of it in a perfect manner. • Most of the water comes from a large stream flowing through his farm, furnishing a never-failing and abundant supply. There are several factories on this stream adding to the value of the water. He uses, also, other smaller streams from the hills which drain from swamps, and this is found less useful. On the large stream Mr. Mitchell has a sawmill, and from the dam connected with it the water is taken. This dam went off two or three years ago, and before it was rebuilt his irrigated fields suffered much, some of the grass dying out entirely. His main ditch is 5 feet wide, about 4 feet deep, and nearly a mile in length. Branching from it is a flume or trough 100 feet or more in length and elevated some 10 feet, carrying a stream of water about 2 feet square across a hollow to an irrigated field. From the main trunks it is led in ditches of various sizes, growing smaller and smaller, until the whole of the water is used up. The whole work requires about 5 miles of ditch. These ditches are mostly elevated, made by embankments rather than excavations, so that by an ingenious contrivance of gates the water can be thrown out at any desired point.

A stream of water as thick as a man's hand, when turned on that dry and hungry soil, will be absorbed in running a few rods, until the ground gets filled up with fine particles from the water. There is no swamp grass there; it is clover and the better kinds of grasses. When I was there, he was mowing his second crop and cutting 1½ tons to the acre, perhaps 2 tons. It is not all as good as that. If there happens to be a little spot of a few feet that, owing to its elevation, is not irrigated at all, it is perfectly barren, and if there happens to be any place where his grade is too low, so that the water stands, it has killed out the grass, and weeds have sprung up, but in general the result is very wonderful and should encourage every one to use what water he can, especially in irrigating that class of lands.

Mr. Mitchell spoke of his orchard which was attacked by the borers. By the help of an embankment he ponded this to a depth of 1 or 2 feet. Though this was continued for several weeks, the trees have survived, and the borers have left. The grading has been done by scraping and carting earth, and by washing. An even surface with a gradual descent so that the water will just flow over the whole is necessary.

Whether all his operations are profitable or not, he accomplishes his purpose, and shows the wonderful effects of the application of water to land of that character.

IRRIGATION PLANTS IN USE IN CONNECTICUT.

There are several irrigation plants in active operation in this State at the present time, located in the towns of Meriden, North Haven, Glastonbury, Hamden, Thomaston, South Manchester, and Simsbury. These are the only ones known to the writer that are operated upon a commercial basis.

IRRIGATION ON THE FARM OF A. J. COE, MERIDEN.

Of the irrigation plants now in operation in this State one of the oldest is on the farm of Mr. A. J. Coe, of Meriden. Mr. Coe says that the work was started by his father about the year 1840, and that the

water was used for many years mainly upon the grass crop, although corn, potatoes, and other crops were irrigated when brought into the rotation, whenever the rainfall was deficient. For the first twenty years it was used mainly on grass and common farm crops. In 1863 Mr. Coe began to use the water on strawberries and raspberries, and has used it every year since whenever drought seemed to make its use necessary. In 1895 he used it on the two crops just mentioned, and upon tomatoes, asparagus, and cabbage.

The source of the water is a small stream that during seasons of average rainfall would just about flow through a 6-inch pipe without pressure. He finds that this stream supplies sufficient water for 15 acres, planted to a variety of crops. The water is stored in two large ponds. The upper one is used mainly for getting ice and to supply power for cutting feed and wood. The smaller pond, a little lower down the stream, is so located that the water can be conducted through a ditch for a distance of about forty rods and then distributed over the field in small ditches. The amount of water is sufficient to thoroughly irrigate a variety of crops if none of them require very large quantities of water during short periods of time.

Mr. Coe has not been able to estimate accurately the profits obtained from irrigation, as the crops grown are used very largely for home consumption. Those sold go to the local markets, which are often overstocked, and prices do not average as high as in some other cities. He, however, is thoroughly convinced that large profits can be obtained from irrigation where the expense of distributing the water upon the land is not too great.

IRRIGATION ON THE FARM OF E. C. WARNER, NORTH HAVEN.

Mr. Warner began his irrigation operations about ten years ago and has used the water mainly for strawberries and raspberries. The cultivated fields are so located that part of them may be watered by flowage from a pond supplied by springs and small streams. Others are on high ground and may be watered from tanks located on a hill near by. A ram is used for filling these tanks, the source of the water being numerous small springs, the water having been conveyed to a common point, making a pond of about one-half of an acre in area. A fall of 6 feet is obtained from the pond to the ram, and the water is lifted 60 feet in height, through 600 feet of pipe to the tanks referred to. As this system is essentially the same as the one described on the farm of Mr. Eddy (p. 19), no detailed description is necessary here. The water is used directly from pipes, being sprinkled upon the soil mainly by means of hose.

On the west side of Mr. Warner's farm a small stream flows through a pasture, and by building small earth dams and ditches the water was conveyed into a pond located a few feet higher than one of the strawberry fields. The fall along the rows of strawberries was very slight most of the distance, and the water was conducted across the rows near

[illegible] turned down the rows [illegible] the field [illegible] so high that the water [illegible] upon a [illegible] was distributed [illegible] then flowed [illegible] the rows again [illegible] Although [illegible] was evident [illegible] was [illegible] of much [illegible] that [illegible] were so [illegible] Septem- [illegible] only a few [illegible] that [illegible] had no [illegible] repre- [illegible] less [illegible] were the [illegible] set [illegible] fall of 1895 [illegible] where [illegible] capacity and water [illegible] about 6 [illegible] directed by direct [illegible]

[illegible] has gotten very benefit [illegible] raspberries [illegible] used it to advantage [illegible] trees in [illegible] during the fruiting season.

[illegible] FARM OF HALE BROS [illegible]

[illegible] of South Glastonbury, growers [illegible] nursery [illegible] the importance of irrigation in their business, and [illegible] been maturing plans for using a supply of water [illegible] purpose. During the fall of 1895 they began [illegible] of the largest systems of irrigation to be found in [illegible]

[illegible] has been dammed, and a reservoir thus formed. The [illegible] about 5,000 feet distant from the fields to be [illegible] about 100 feet. Heavy cast iron pipe 6 inches [illegible] together with lead, were used for 300 feet from the [illegible] 4 inch pipe for 1,900 feet, or until a fall of 50 feet [illegible] which the size of the pipe was reduced to 3 inches. [illegible] along the top of the ridges of the farm, and at [illegible] apart hydrants were placed so that the water can [illegible] pipe and used for surface flowage or for sprink- [illegible] there is sufficient water to thoroughly irrigate [illegible] mainly by surface irrigation. The contour [illegible] character of the soil are such that water can be [illegible] the rows of plants and trees so as to give a very [illegible]

The [illegible] propose to use the water on small fruits, and ulti- mately [illegible] thoroughly convinced from experience that

the use of water on peach trees will prove profitable in seasons of severe drought during the fruiting time.

IRRIGATION ON THE FARM OF JOHN LEEK, HAMDEN.

On this farm there are about 5 acres under irrigation at the present time. The land is low, nearly level, lying between the slopes of hills, and a small stream of water passes through the irrigated area near the center. The surface soil is a fine, gravelly loam that has apparently been washed in from the surrounding hills. At a depth of about 3 feet is a gravelly clay hardpan, beneath which is a stiff clay.

The land is naturally quite fertile, but the compact subsoil prevents the escape of surplus water, while in case of drought the land bakes and cracks badly. The physical condition of the soil has been greatly improved by drainage. The texture of the soil is firm enough to prevent washing, and the fall is about 3 feet to 100, so that conditions are favorable for surface flowage from open ditches.

A small stream of water that would, in times of an average flow, readily pass through a 5-inch pipe enters the farm through a narrow ravine, and has a fall of about 15 feet for the first 20 rods back from the irrigated area. About 15 rods up this ravine has been built a dam and a small storage pond, from which the water is conveyed in open ditches upon different parts of the field.

The whole area has been laid out in three lots in such a way that water can be conveyed to the ends of the fields and allowed to run down between the rows of the crops, some of the land having been graded in order to make this practicable. The water has, in a small way, been used on a variety of garden crops, but quite extensively on strawberries and celery. Mr. Leek is so well pleased with the results on these crops that he is planning to enlarge his storage pond and to use the water more extensively in the future.

The conditions on this farm are similar to those found on many Connecticut farms, in that the water can be obtained for irrigation at a nominal cost.

IRRIGATION ON THE FARM OF W. A. LEIGH, THOMASTON.

This farm is located in the Naugatuck Valley, at the base of a steep bluff that rises, quite abruptly, about 350 feet above the valley. Over this bluff pours a small mountain stream that is quite constant and of volume about sufficient to fill a 6-inch pipe in times of an average flow. This stream is fed by springs near the top of the bluff. By building a dam across a narrow ravine a storage pond covering an area of about 5 acres was formed, 300 feet above the irrigated fields.

The water is conducted through a 3-inch pipe laid on the surface of the ground, and is used in furnishing power for a small granite works as well as for irrigating. The pressure is so great—about 125 pounds to the square inch—that a small stream runs a water wheel furnishing 7 horsepower. The water is used for irrigating mainly at night.

one end and turned down the rows as needed. At one point in the field there was a knoll so high that the water could not be gotten upon a small area, but it was conducted around the knoll, and it then flowed readily along the rows again and over the rest of the field. Although no attempt was made to estimate the differences in yield, it was evident that the crop on this knoll was very much smaller and the fruit of much poorer quality than over the rest of the field. The plants also were so much injured by the effects of the drought that when seen in September, 1895, they presented a striking contrast to the plants only a few feet away where the water had been used. Mr. Warner thinks that the crop on the whole field was double what it would have been had no artificial watering been done. The entire expense of irrigation represented only a few days' work with men and teams, probably costing less than $25 when estimated at market rates of labor. So great were the benefits derived from this small effort that Mr. Warner at once set about making plans to enlarge his system, and during the fall of 1895 he built two large storage ponds a little higher up the stream, where he expects to have storage capacity and water sufficient for about 6 acres, all of which can be watered by direct flowage.

While Mr. Warner has gotten very beneficial results on raspberries with irrigation, he has also used it to advantage upon peach trees in times of severe drought during the fruiting season.

IRRIGATION ON THE FARM OF HALE BROS., SOUTH GLASTONBURY.

The Hale Brothers, of South Glastonbury, growers of fruit and nursery stock, have long felt the importance of irrigation in their business, and have for some time been maturing plans for using a supply of water near their farm for this purpose. During the fall of 1895 they began the laying out of one of the largest systems of irrigation to be found in the State.

A small brook has been dammed, and a reservoir thus formed. The source of the water is about 5,000 feet distant from the fields to be irrigated, and the fall is about 100 feet. Heavy cast-iron pipe 6 inches in diameter, joined together with lead, were used for 360 feet from the reservoir, and then a 4-inch pipe for 1,900 feet, or until a fall of 50 feet was obtained, after which the size of the pipe was reduced to 3 inches. The pipe was carried along the top of the ridges of the farm, and at points about 200 feet apart hydrants were placed so that the water can be taken from the main pipe and used for surface flowage or for sprinkling. It is believed that there is sufficient water to thoroughly irrigate from 45 to 50 acres of land mainly by surface irrigation. The contour of the land and the character of the soil are such that water can be distributed between the rows of plants and trees so as to give a very even distribution.

The Messrs. Hale propose to use the water on small fruits, and ultimately on peaches, being thoroughly convinced from experience that

the use of water on peach trees will prove profitable in seasons of severe drought during the fruiting time.

IRRIGATION ON THE FARM OF JOHN LEEK, HAMDEN.

On this farm there are about 5 acres under irrigation at the present time. The land is low, nearly level, lying between the slopes of hills, and a small stream of water passes through the irrigated area near the center. The surface soil is a fine, gravelly loam that has apparently been washed in from the surrounding hills. At a depth of about 3 feet is a gravelly clay hardpan, beneath which is a stiff clay.

The land is naturally quite fertile, but the compact subsoil prevents the escape of surplus water, while in case of drought the land bakes and cracks badly. The physical condition of the soil has been greatly improved by drainage. The texture of the soil is firm enough to prevent washing, and the fall is about 3 feet to 100, so that conditions are favorable for surface flowage from open ditches.

A small stream of water that would, in times of an average flow, readily pass through a 5-inch pipe enters the farm through a narrow ravine, and has a fall of about 15 feet for the first 20 rods back from the irrigated area. About 15 rods up this ravine has been built a dam and a small storage pond, from which the water is conveyed in open ditches upon different parts of the field.

The whole area has been laid out in three lots in such a way that water can be conveyed to the ends of the fields and allowed to run down between the rows of the crops, some of the land having been graded in order to make this practicable. The water has, in a small way, been used on a variety of garden crops, but quite extensively on strawberries and celery. Mr. Leek is so well pleased with the results on these crops that he is planning to enlarge his storage pond and to use the water more extensively in the future.

The conditions on this farm are similar to those found on many Connecticut farms, in that the water can be obtained for irrigation at a nominal cost.

IRRIGATION ON THE FARM OF W. A. LEIGH, THOMASTON.

This farm is located in the Naugatuck Valley, at the base of a steep bluff that rises, quite abruptly, about 350 feet above the valley. Over this bluff pours a small mountain stream that is quite constant and of volume about sufficient to fill a 6-inch pipe in times of an average flow. This stream is fed by springs near the top of the bluff. By building a dam across a narrow ravine a storage pond covering an area of about 5 acres was formed, 300 feet above the irrigated fields.

The water is conducted through a 3-inch pipe laid on the surface of the ground, and is used in furnishing power for a small granite works as well as for irrigating. The pressure is so great—about 125 pounds to the square inch—that a small stream runs a water wheel furnishing 7 horsepower. The water is used for irrigating mainly at night.

For irrigating purposes branch pipes of 1½ and 1 inch in diameter are laid on the surface of the ground, the lines of pipe being placed about 50 feet apart. Short pieces of hose are attached to these lines of pipe, once in about 50 feet, and the water is applied by spraying through ⅜-inch nozzles. The pressure is so great that three or four of these ⅜-inch streams may be kept playing at one time from a single pipe. The water is forced to a great height and spreads out into a fine spray, covering a large area, like a lively shower.

Mr. Leigh has about 15 acres upon which irrigation might be applied. Its use, however, has been confined to strawberries. He began using the water on this crop in 1887 and has used it every year since. In 1895 about 3 acres were under irrigation.

The water is first used about the time the plants bloom and is continued if needed till near the end of the fruiting season. Mr. Leigh prefers to apply the water largely at night, as he finds it blackens or "blights" the leaves if used near the middle of the day when the sun shines brightly. No accurate comparisons as to the yields with and without irrigation have been made, but Mr. Leigh estimates that double the crop has been obtained as a result of the free use of water.

IRRIGATION ON THE FARM OF JOSEPH ALBISTON, SOUTH MANCHESTER.

Mr. Albiston probably has the oldest irrigation plant in Connecticut. The privilege was granted in 1796, the water being taken from a small stream at a point about 60 rods above the limits of the farm. The stream is of sufficient size to about fill a 10 or 12 inch pipe in times of an average flow. The brook passes through part of the farm, and about 7 acres of land either side of the stream can be watered. There are two small irrigation plants now in use on the farm. In the oldest the water is conveyed in an open ditch. The fall of the stream is such that at a very small expense for a dam practically all of the water of the stream can be turned into the ditch. About 5 acres can be watered by this means. This plant was very extensively used in irrigating grass for many years, but within the past twenty years it has been used to water small fruits and vegetables.

A second plan of irrigation was adopted, for a part of the farm, a few years ago. At a point near where the same brook just referred to enters the farm a dam and small pond were constructed. They are now used in irrigating about 2 acres of the bottom land along the brook.

Most of the soil of the irrigated area is a gravelly loam, much of which has been washed down from the surrounding hills. About 2 acres of the bottom lands are of a more compact soil, with a hardpan subsoil. This area has been underdrained and much improved. The surplus water used in irrigation is now readily conveyed away through the underdrains.

Of the area watered from the canal about 3 acres are nearly level, having a fall of less than 5 feet in 400. The water can be conveyed by

a branch ditch along one end of this area and then, as needed, turned down between the rows of small fruits and vegetables. About 1 acre on quite a steep slope just below the main ditch is thoroughly watered by seepage from the canal.

Mr. Albiston has found the use of irrigation especially profitable on strawberries. In 1894 32 square rods of land planted with Crescent strawberries produced at the rate of 10,400 quarts per acre. In 1895, with a very severe drought at the time of fruiting, Mr. Albiston claims that his crop was the best that he has ever produced. The blackcap raspberries and blackberries have each year produced exceptionally fine crops under irrigation. Potatoes have been irrigated during seasons of drought. In 1894, which was an exceptionally unfavorable season for potatoes, the crop obtained by irrigation yielded at the rate of 300 bushels to the acre.

IRRIGATION ON THE FARM OF J. C. EDDY, SIMSBURY.

Mr. Eddy is making a specialty of small fruits and vegetables, and the severe droughts which have occurred each summer for the past three or four years have impressed upon his mind the great importance of an abundance of water for the financial success of his business. The farm is located near the western limits of the Connecticut Valley, and is composed mainly of a light, porous, rather sandy soil that requires large quantities of water to grow crops successfully. A small stream within a narrow valley passes through the farm, and the cultivated lands lie mainly upon slopes just outside this valley. The water of the stream is not very cold, and the temperature is raised somewhat by allowing the water to stand in a storage pond where a large surface is exposed to the direct rays of the sun. The water appears to contain quite a little organic matter, and doubtless furnishes considerable plant food.

It has been found impossible to bring the water upon any save a small portion of the farm by damming the stream and building ditches, and it would have cost quite a sum to have gotten the right of way, as the water would need to be taken from a point beyond the limits of the farm; therefore, a ram was adopted as the most feasible means of making the water available for irrigation. In order to get the necessary fall for running the ram, a canal about 40 rods in length was dug along the outer edge of the valley. From the lower end of this canal the water makes a fall of 7 feet through a 6-inch drive pipe and forces a large ram located near the center of the valley. The water was turned into the canal by a small and inexpensive wooden dam. No more water is allowed to enter the canal than can be carried off through the drive pipe of the ram. The supply that flows in the brook is many times the amount that even the heaviest form of ram could lift.

At quite an elevation above the cultivated fields, on soil of a heavy, clayey nature, was located a small pond that usually became dry in summer. This was enlarged by dredging and by building an earth dam

on two sides. A storage pond was thus provided having an area of about half an acre and an average depth of about 4 feet, with a bottom tight enough to prevent much soakage. This pond is located about 80 rods from the stream at the nearest point, and high enough to give a good fall to most of the cultivated fields.

The water has to be lifted to a height of 70 feet before it enters the storage pond and is conducted through a 2½-inch iron pipe. Connections can be made with this pipe at various points between the ram and

Fig. 1.—Irrigation system on the farm of J. C. Eddy, Simsbury, Conn.

the storage pond, and thus the same pipe can be used to conduct the water to the pond or directly to the fields where needed for use. The main pipe used is 2½ inches in diameter, and is laid sufficiently deep not to interfere with cultivation. Mr. Eddy has been so successful in his operations during 1895 that he proposes to enlarge his plant and to force the water over a large area of land planted in peaches on the opposite side of the valley from the storage pond.

The accompanying plan of Mr. Eddy's farm will give a clear idea of

the position of the ram, the storage pond, the lines of pipe, and the various fields upon which the water may be used. The different fields upon which the water was used in 1895, as well as some of the fields where it is proposed to use it are marked out by dotted lines. It will be noticed that the land on either side of the brook to the east of the pond slopes rapidly toward the valley. The slope is here so great and the soil of such a porous nature that the water can only be applied by sprinkling from hose. The proposed line of pipe to the high ground east of the valley is indicated by dotted lines.

The fields to the north of the farm buildings are watered through pipes directly from the storage pond.

Two acres of strawberries on the west side, which were irrigated during the season of 1895, were on soil of such a slope that either surface flowage or sprinkling could be used. Water is wanted in large quantities on strawberries during short periods of time.

The crops grown and successfully irrigated by Mr. Eddy during 1895 were strawberries, muskmelons, onions, and cauliflower. These have proven especially important crops because of their high value per acre and the fact that the farm is located at quite a distance from markets, where bulky crops giving smaller profits per acre would be expensive to market. With this variety of crops the water would not be needed in very heavy quantities at any one time during the season, unless it might be for a few days during the fruiting season of the strawberries.

Results of irrigation on strawberries.—Mr. Eddy had 4 acres of strawberries in 1895. Two of these were located on high ground at the east side of the farm and could not be irrigated, and the other two on quite low ground north of the buildings. A severe frost in May appeared to have destroyed many of the blossoms and lessened the crop prospects very decidedly for the 2 acres located on low ground, while but little damage resulted to those on the high ground. Owing to this condition larger returns were to be expected from the field located on high ground, provided rainfall had been abundant. As it was, however, a drought began early in June and seriously reduced the strawberry crop all over the State. At the end of the season it was found that the 2 acres which were not irrigated gave a yield of 150 crates (32 quarts each), while the 2 acres that were irrigated yielded 415 crates. After the first few days' picking, the fruit on the unirrigated field was much smaller and darker colored and averaged only about 8 cents a quart for the season, while that from the irrigated field averaged 11 cents a quart. It must be remembered, however, that the fruit from the unirrigated field had to be sold when the markets were heavily stocked with berries, while much of that from the irrigated area reached the market after prices had risen, owing to the general shortage from the effects of the drought.

The water was not applied until just before the picking season opened, although better results would probably have been obtained had the water been used two weeks earlier. The method of applying first adopted was surface flowage, but owing to the mulch between the

rows it was found that this method was a very slow one. For this reason the plan of sprinkling from hose was adopted. Condemned 2-inch fire hose, with a large sprinkler attached, was used. This would throw a powerful spray, covering an area about 20 feet in diameter. The pressure was sufficient to give a flow of 30 gallons per minute. With this flow it was found that one man could water an acre thoroughly in about ten hours.

Later experience (1896) shows better results by the temporary removal of the mulch and the application of the water by flowage.

Results on muskmelons.—When grown on light soil and forced along rapidly early in the season, muskmelons have generally proved a very valuable crop in this State. Much loss, however, has been occasioned by frosts before much of the fruit is in condition to market. It is claimed that by irrigation it is possible to get the melons into market considerably earlier than usual, and to get large crops before killing frosts occur. As the plants only cover a small portion of the ground early in the season, sprinkling seems to be the best method of applying the water, and where the soil is loose and porous, with considerable fall, sprinkling is without doubt the best method for the entire season. By applying water once in five or six days, when a lack of rainfall seemed to make it necessary, it is thought that a steady growth of the vines and an earlier and much larger crop was secured than could have been obtained without artificial watering. It appears also that irrigation may have had influence in improving the flavor of the fruit. This may be a valuable feature of irrigation upon this crop; however, further investigation will be necessary to establish it. The melon crop grown upon 1 acre by irrigation sold for $350, and the vines were "full of fruit" when they were killed by frost September 14.

Results on onions.—This crop did not suffer materially from drought during 1895 in this State. Mr. Eddy's crop, however, was grown upon very light soil, and the ground was thoroughly sprinkled once during the growing season. A small portion of the field could not be reached with the hose, and this was allowed to go without artificial watering. No measurements of the crop were made, but when visited by the writer while the crop was being harvested considerable difference could be seen between the crop on the irrigated land and that on the small strip that was not irrigated. One thing especially noticeable in addition to the smaller yield was the increased proportion of small onions where no water had been used.

Results on cauliflower.—About 1 acre of this crop was grown during 1895. The crop was grown on a field of medium-heavy loam only a few feet above the bottom lands of the valley. The fall across the field, lengthwise of the rows, was at the rate of 3 feet per hundred, and the water was applied to this crop by allowing it to flow between the rows. From a 2½-inch pipe, with a 2 inch hose, about 40 gallons of water per minute could be obtained, and only about eleven minutes were required

for the water to flow from one end of the rows to the other, a distance of 175 feet. The water was applied once in about five or six days if the lack of rainfall seemed to make it necessary. The cauliflower headed earlier than usual, and the crop sold readily at about $400 per acre.

EXPERIMENTS ON THE EFFECTS OF IRRIGATION ON STRAWBERRIES.

In June, 1895, the Connecticut Storrs Station began some experiments on the farm of Mr. Eddy, for the purpose of studying the effects of irrigation on the quantity and quality of strawberries, and to ascertain some facts regarding the profits to be obtained from the use of irrigation.

It is hoped that this will be the beginning of a series of experiments by this station on the effects of irrigation on a variety of crops. There are many questions that it seems desirable to investigate in connection with the subject, such as the different methods of applying water and the relative advantage of each, observations on soil temperature, determination of the amount of plant food supplied in the water used, and chemical analyses of fruits grown, for the purpose of determining the amounts of sugar in irrigated and unirrigated crops.

The work was undertaken so late in the season that observations were made only on the yield, and on the quality of the crop, as indicated by taste, appearance, and market value.

PLAN OF THE EXPERIMENT.

A section was chosen from a field of strawberries of about 2 acres in area. The soil appeared to be nearly uniform, and the conditions were favorable for applying the water. The field had been set to strawberries in the spring of 1894. The Haverland was the variety used, with every fourth plant in the row a Jessie, the latter being used for fertilizing the Haverlands. The plats were 115 feet long and 12 feet wide, three rows to a plat, two plats being irrigated and two not irrigated. Two rows were left between plats which were not included in the experiment, in order to thoroughly separate the irrigated from the unirrigated sections. The plats were to be irrigated as often as seemed to be necessary to get good commercial results.

RESULTS.

The following table gives the yields in quarts and pounds for each day when fruit was picked.

Yields of strawberries on irrigated and unirrigated plats.

Date.	Plat 1, irrigated.[1]		Plat 2, unirrigated.		Plat 3, irrigated.[1]		Plat 4, unirrigated.	
1895.	*Quarts.*	*Pounds.*	*Quarts.*	*Pounds.*	*Quarts.*	*Pounds.*	*Quarts.*	*Pounds.*
June 13	1.1	[2]1.6	4.0	[2]5.6	3.9	[2]5.5	3.0	[2]4.2
14	4.0	[2]6.0	6.0	[2]8.4	4.0	[2]5.6	6.0	[2]8.4
15	12.0	[2]18.0	12.0	[2]16.8	13.0	[2]18.2	6.5	[2]9.1
17	19.5	29.1	18.0	25.6	25.0	34.8	18.0	24.9
18	14.0	19.1	6.0	8.0	14.0	17.9	3.5	4.9
19	14.0	19.1	5.0	6.5	17.0	23.2	4.5	6.5
20	21.0	27.8	3.0	4.0	12.0	15.7	3.0	4.3
21	16.5	22.2	3.0	3.2	11.8	14.8	3.0	3.6
22	10.0	12.4	3.0	4.4	6.0	7.4	5.0	5.1
24	25.0	34.0	4.5	5.3	(3)	(3)	(3)	(3)
25	[4]6.0	[4]8.4	[4]1.5	1.8	32.0	42.7	5.0	6.8
26	14.0	20.8	1.3	1.7	7.0	10.1	2.0	3.0
27	9.0	12.2	1.0	1.0	3.5	4.7	1.0	1.0
29	4.0	5.5	1.0	1.1	3.5	4.9	1.0	1.4
July 2	5.5	7.9	.5	.8	6.0	8.3	.5	.9
5	2.0	2.4	....	....	1.0	1.4	....	....
Total	177.6	246.5	69.8	94.2	159.7	215.2	62.0	84.1

[1] Watered June 10, 15, 18, and 20 and 21.
[2] Assumed to weigh same rate per quart as on June 17.
[3] Not picked.
[4] Not all picked.

Most of the picking was done by a representative of the station, as often as seemed necessary to have the fruit in good market condition. In case of the first three pickings no facilities were on hand for weighing, and the fruit was estimated to weigh the same per quart as that of the next succeeding picking. The weights per plat were figured from these data. All of the other pickings were both measured and weighed.

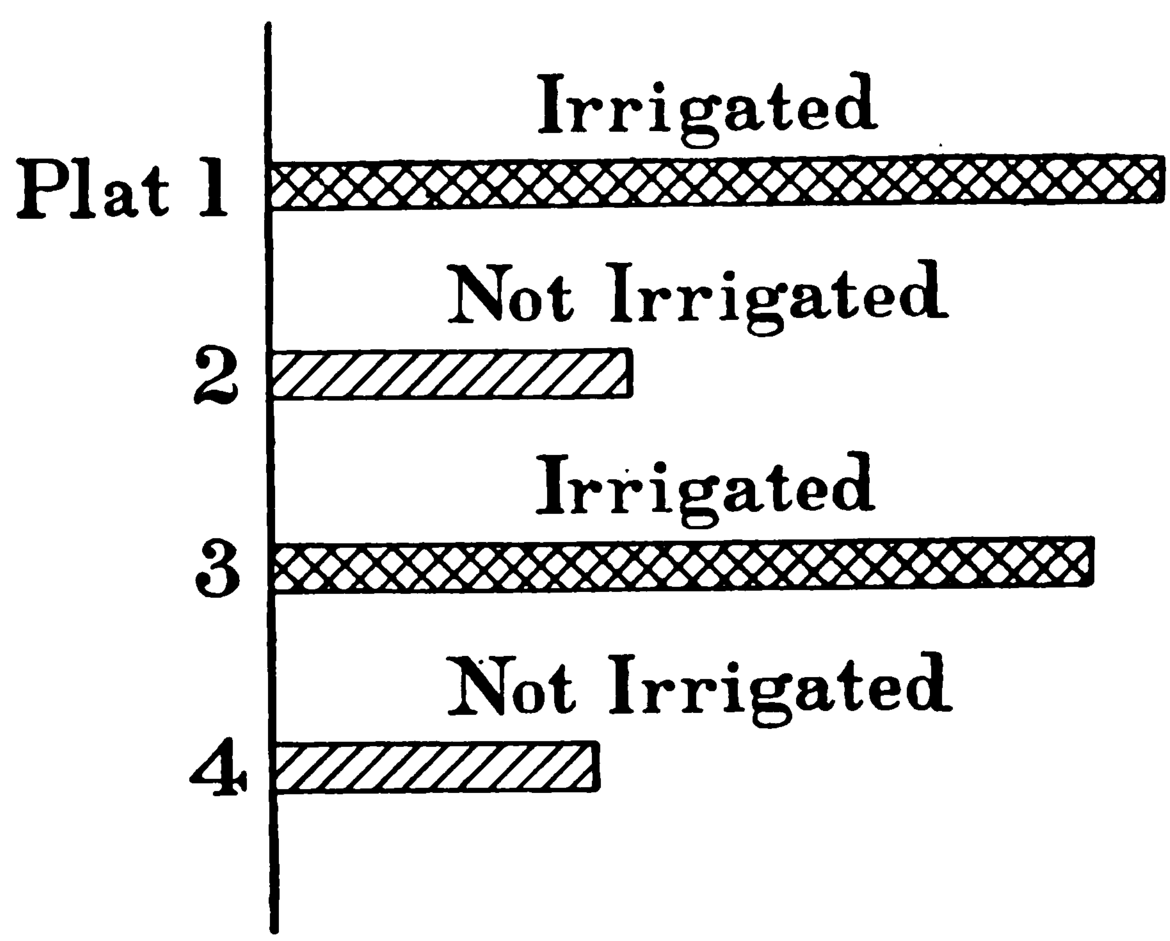

FIG. 2.—Comparative yields of strawberries on irrigated and unirrigated plats, 1895.

The effects of irrigating on the yield of strawberries is shown graphically in the accompanying diagram.

Water was used on the irrigated plats on June 10, 15, 18, and 20. The water was applied by means of 2-inch hose from a 2½-inch iron pipe laid on the surface of the ground. The size of the stream and the force of the water was sufficient to give 30 gallons (about 1 barrel) per minute. At this rate of flow one man could water, by sprinkling, about 1 acre per day. The ground was given a thorough wetting each time.

There was very little rainfall during the first twenty-five days of June. Seven-tenths of an inch fell between the 2d and 6th, but from the 6th to the 22d no rain whatever fell; on the 22d there was 0.25 inch, and after the 25th of the month rain was quite abundant. Strawberries generally began to feel the effects of the drought by June 17, before the picking season was more than one-third through.

It will be noticed that for the first two pickings the results were in favor of the unirrigated plats, and that the yields on the unirrigated plats were nearly as great as on the irrigated until after June 17. For the second picking (June 14) the two watered plats only gave 8 quarts, while the two not watered yielded 12 quarts. This tends to show that irrigation retards the development of the fruit and causes it to ripen a little later. The same condition was noticed on the larger fields of this farm. During the first few pickings the fruits from the unwatered plats were found to be sweeter, but those from the watered plats were larger and "looked 3 cents per quart better."

On June 17 the leaves of the plants on the unirrigated plats began to wilt and the berries to shrivel. The plants on the unwatered plats continued to dry, the leaves began to fall, and the fruit was small, dark colored, shriveled, and seedy.

On June 24 the writer visited the fields and found the plants on the unirrigated plats drying badly; leaves shriveled and many dry and dead; fruit much smaller, darker colored when ripe, and shriveled and seedy; hulls shriveled, and fruit appearing overripe when picked.

On the other hand, plants on the irrigated plats looked fresh and vigorous, the berries were large, bright colored, and abundant, and much green fruit was developing. The fruit, however, was not quite as sweet as on the unirrigated plats.

The total yield on the two irrigated plats was 337 quarts and on two unirrigated 132 quarts. This was at the rate of 5,318 quarts for the irrigated and 2,083 quarts for the unirrigated. The fruit from the unirrigated plats had to be sold for an average of 9 cents per quart, while that from the irrigated areas brought 11 cents. At these rates per quart the fruit on the irrigated plats sold at the rate of $584.76 per acre and that on the unirrigated at the rate of $187.47 per acre, a difference of $397.29 per acre in favor of irrigation.

It will be readily seen that with only 2 acres of strawberries the increased returns obtained, during one season by the use of water, would afford quite a sum toward covering the expense of an irrigation plant.

SUGGESTIONS REGARDING IRRIGATION.

The surface contour of most of the land of Connecticut, and in fact of all New England, is such as to facilitate the utilization of water for irrigation. The land is undulating and of such a slope as to readily admit of the conveyance and application of water. Streams, ponds, and springs are common, and except in cases of severe droughts these

furnish an adequate supply of water for irrigating. Many crops like strawberries, raspberries, and early vegetables need irrigating, if at all, early in the season. The supply of water is then often sufficient, when perhaps later in the season it would not be ample. Much of the land that would be improved by irrigation is found in valleys, in the proximity of streams and ponds, which in many cases are high enough for the water to be applied by gravity on the areas below, and the cost of getting the water is merely nominal. The soils used for our most profitable crops are generally light, porous, and leachy, and are just the class of soils that need irrigating; while our best money crops, such as small fruits and vegetables, commonly grown on these soils, are heavy users of water. There is no need of drainage in connection with irrigation on soils of this class, as is often the case where the subsoil is compact.

SOURCES OF WATER AND MEANS OF MAKING IT AVAILABLE.

The sources of water for irrigation in Connecticut are natural ponds, streams, springs, and wells. In many cases ponds are so located that water can be conveyed from them to fields on lower ground by means of open ditches. The expense for conveying the water will depend upon the distance and the character of the ground to be passed through. This is often the cheapest method for securing water. When the supply is great the loss of water occasioned by seepage from the ditch, or by evaporation is not of serious consequence. There are a few ponds in the State where by piping over higher ground and then on to land below the surface of the pond the water can be siphoned over and thus made available.

The fall of many of the small streams is so great that by building a dam the water might be turned from its natural course and conveyed in ditches along the outer edge of the valley and then allowed to flow over the surface of the fields back of the natural stream. In many cases the water running away from mills might be applied by flowage. The water from several springs may sometimes be conveyed to a single point and then held in a small pond from which it may be drawn as needed. Where only small areas are to be irrigated, wells may be made a source of water supply. The well must afford a large flow and should be so located that the water can be stored at some point at least 25 feet above the fields to be watered. In many cases bored wells might be utilized and afford a heavy flow of water.

IRRIGATION IN NEW JERSEY.

By Edward B. Voorhees, M. A.,

Director of the New Jersey Agricultural Experiment Stations and Professor of Agriculture in Rutgers College

INTRODUCTION.

The question of irrigation in what are regarded as the humid, or regions of sufficient annual rainfall of this country, is beginning to receive considerable attention, and the interest now aroused may be traced rather to changes which have taken place in the character of the farming than in any marked changes in the character of the seasons and in the annual rainfall.

In New Jersey, as well as in other Eastern States contiguous to the large cities, there has been a rapid increase in the area devoted to market garden products, fruits and berries, or crops of relatively high value, and a corresponding decrease in the area devoted to old line farming, or to crops of comparatively low value. This change in the nature of the crops grown is, as a rule, accompanied by a change in practice, that is, what is known as the "intensive" system of farming is more largely adopted; large quantities of manures are applied and crops rapidly succeed each other, all supplied with an abundance of food. Fu thermore, earliness and high quality of products are of relatively greater financial importance than formerly, and these conditions can not be secured without a continuous and abundant supply of water. The wider dissemination of accurate information concerning the principles which govern in the management of soils and in the feeding of crops and the means now afforded for combating insects and diseases enable the producer at the present time to largely control the conditions other than weather. The late frost in spring and early frost in autumn, floods, and the spring and midsummer droughts are still beyond his control, and the frequency of the latter are the cause of very great losses annually.

The lack of water, particularly for quick-growing vegetables, small fruits, and berries, not only seriously affects both their yield and quality, but many times causes complete failure. The necessity of utilizing all the means at hand for overcoming these difficulties is, therefore, apparent and *justifies* a careful inquiry concerning the possibilities of

irrigation in those regions in which crops are more or less injured from year to year either through a lack of sufficient rainfall or through its unequal distribution.

In carrying out the investigations here recorded, particular inquiry was made along the following lines: (1) Need of irrigation in New Jersey; (2) areas capable of being watered by gravity and accessible water supply for this purpose; (3) estimated cost of irrigation; (4) use of irrigation in the State, methods used, and the results secured; and (5) irrigation experiments in New Jersey.

The meteorological records of the State afford abundant proof that there is very frequently a shortage of water during the growing season, due both to a deficiency in rainfall and to its unequal distribution, and that the most serious shortage occurs in those sections peculiarly adapted for the growth of vegetables and small fruits.

The data in reference to rainfall, in connection with careful measurements of the flow of streams, show that the State possesses a large supply of water for purposes of irrigation, which careful surveys indicate may be made accessible at a reasonable expense.

That this valuable resource of the State may be utilized with profit is illustrated by the examples given, derived from actual experience. The financial returns secured in these cases were profitable, even though those engaged in the work were inexperienced in all matters pertaining to irrigation. With proper knowledge of methods, the advantages derived doubtless would have been very much greater.

The experimental plant now in operation on the farm connected with the New Jersey stations has for its object the study of the necessity of irrigation for a wide variety of crops, the amount of water required, and the various methods of application.

NEED OF IRRIGATION IN NEW JERSEY.

The need of irrigation in some portions of the State has been seriously felt several times during the past fifteen years, and especially during the year 1895, which is still fresh in memory. This need is not so apparent when we merely consider the average rainfall throughout the State, which varies from 44.09 inches in the northwest to 49.70 inches on the seacoast, the main law of change observable being a quite steady decrease as we go inland from the coast. It is, nevertheless, a fact, that our entire rainfall occasionally sinks to 31.5 inches in some localities, or as low as the annual rainfall on the borders of the subhumid region of the West, and also that droughts occur during the growing months from April to August, inclusive, even more frequently than is popularly supposed. If even one of these months shows a serious deficiency of rainfall below the average, some crop is likely to suffer. In order to show how often this has occurred in the past a table has been compiled from the longer series of rainfall records obtainable,

which shows what percentage of the years covered by the records in each case show a deficiency of 1 inch or more below the average rainfall:

Percentage of years in which rainfall during growing season has been 1 inch or more below the average.

	Years of record.	April.	May.	June.	July.	August.	Deficiency for— One month.	Deficiency for— Two months.	Deficiency for— Three months.
New York	1836-1895	33	35	35	33	39	75	42	21
Newark	1844-1895	32	28	36	40	32	....	....	....
New Brunswick	1854-1895	35	28	32	47	40	....	....	....
Philadelphia	1825-1895	34	32	32	37	38	88	56	30
Moorestown	1879-1895	7	27	27	33	27	....	....	....
Vineland	1868-1895	2	34	29	50	40	....	....	....

Taking each month by itself, we find that the longer records show generally that the deficiency occurs about one-third of the time. The fact that it is less for Moorestown and Vineland for certain months is probably due only to the shortness of the records. The second part of the table shows a fact which is more serious, namely, that during the seventy years covered by the Philadelphia record, 88 per cent of the years show at least one month of this critical period deficient, while 56 per cent show two or more months deficient, and 30 per cent three or more months. The only reason that New York shows a less proportion is that the record does not include the years from 1825 to 1835, which were dry ones. After a careful analysis of all the rainfall records of the State we are convinced that during this period of seventy years any part of the State would have been subject to as great and as frequent droughts as are shown by the Philadelphia records.

Observation confirms what we should naturally expect, that our average rainfall is that which is most conducive to luxuriant vegetation, that is, to good crops. We should expect this because this average represents conditions which have generally caused our State to be productive. If we turn to the records of rainfall we find that those years which approximate the average in amount and distribution of the rainfall have almost invariably been very productive ones.

We find from our rainfall records that the period from 1860 to 1866 shows a remarkably uniform rainfall during the growing months, generally close to the average. In the following table the rainfall for certain notably dry years of recent occurrence, with the average rainfall for certain stations which fairly represent the State, is shown.

Rainfall of average and of some deficient years.

NEWARK.

	April to August.	Spring.	Summer.	Year.
	Inches.	*Inches.*	*Inches.*	*Inches.*
1880	17.38	8.96	13.32	37.34
1881	11.28	11.45	6.66	39.00
1882	14.61	10.89	6.91	51.70
1885	14.94	6.49	10.48	43.59
1894	10.42	7.69	4.62	40.60
1895	19.14	10.00	11.88	39.53
Average	20.38	11.46	12.83	46.70

Rainfall of average and of some deficient years—Continued.

NEW BRUNSWICK.

	April to August.	Spring.	Summer.	Year.
	Inches.	*Inches.*	*Inches.*	*Inches.*
1880	17.79	7.90	14.76	37.17
1881	11.32	8.42	8.47	38.46
1882	15.86	10.76	7.72	48.66
1885	15.41	5.23	11.26	36.70
1894	16.43	11.02	7.00	48.06
1895	10.68	10.68	11.62	39.25
Average	21.34	11.37	13.74	46.89

PHILADELPHIA.

	April to August.	Spring.	Summer.	Year.
1880	17.47	6.50	14.50	33.58
1881	9.33	7.15	6.01	30.21
1882	16.85	10.75	9.67	45.58
1885	16.19	6.99	9.89	33.35
1894[1]	23.12	18.56	6.70	55.68
1895[1]	16.38	11.73	8.62	35.90
Average	19.89	10.74	12.48	43.35

VINELAND.

	April to August.	Spring.	Summer.	Year.
1880	22.63	10.95	18.03	51.71
1881	13.01	10.10	8.18	42.48
1882	20.26	11.69	12.88	54.01
1885	13.16	6.36	7.71	35.43
1894	24.62	18.72	7.71	55.19
1895	17.49	13.48	8.09	38.36
Average	19.69	11.22	12.98	47.87

[1] Moorestown.

For the first four of these years the relative severity of the droughts is well exhibited by the deficiency of the rainfall for the five growing months from April to August. In 1881, the driest year of all, this deficiency ranged from 9 to 10.5 inches, although Vineland shows but about 7 inches. The year 1885 shows generally about 6.5 inches deficiency. The years 1881 and 1894 were so dry as to cause the forests in the northern part of the State to turn brown, and numbers of trees were actually killed, showing that the limit of endurance of the forests had about been reached. We find that at Newark the deficiency from April to August was 9.1 inches in 1881, and 9.96 inches in 1894. The average deficiency for the northeastern part of the State was probably about the same for both years. The severity of the drought of 1894 is not well shown in the rainfall from April to August at New Brunswick, Philadelphia, and Vineland, but taking the summer rainfall alone it becomes more apparent. So in 1895, the tables fail to show the full severity of the drought, but the following table exhibits it more satisfactorily for both these years:

Rainfall during droughts of 1894 and 1895.

	May to August—			June to August—		
	1895.	Average.	Deficit.	1894.	Average.	Deficit.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Kittatinny and highlands	13.92	16.23	2.31	5.21	12.35	7.14
Red sandstone plain	14.87	16.90	2.13	6.43	12.86	6.43
Southern interior	11.45	17.82	6.37	6.95	13.22	6.27

This table is made up from the average of a large number of stations for each district, taken from the records of the State Weather Service, to which we are indebted for much of our data. The drought of 1894 was confined to the summer months, and was slightly more severe in northern than in southern New Jersey when measured by the deficiency of rainfall alone. The drought of 1895 was much less severe in northern than in southern New Jersey owing to the fact that it set in one month later, September showing about 1 inch of rainfall, while the deficiency up to the end of August had only been about 2 inches, whereas in southern New Jersey August showed only about 1 inch of rainfall and September the same amount. It is interesting to compare the amount of rainfall shown in these tables with that of western Kansas, where the mean annual temperature is about the same as that of southern New Jersey, and where irrigation has been found to be necessary for profitable agriculture. In those places at which the average rainfall is about 20 inches per annum, that of spring is 4.7 inches, and that of summer 7.9 inches, making a total of 12.6 inches for the two seasons. It will be seen that the above dry periods approach these figures. Another interesting comparison is that of the next table, which is compiled from the report of the Kansas State Board of Agriculture.[1] This shows the rainfall and crop conditions where the average yearly rainfall happens to be almost exactly that of our driest years. It will be seen that from April to August the average rainfall of this region is 20.50 inches, while that of the Kittatinny Valley and highlands is 19.75 inches, the red sandstone plain 20.53 inches, and the southern interior 21.67 inches for the same months. The temperature is also much the same as that of our southern interior.

Rainfall and crop conditions, Riley County, Kans.

Year.	Rainfall.				Yield per acre.			
	April to August.	Spring.	Summer.	Year.	Wheat.	Corn.	Oats.	Potatoes.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
1872	24.84	9.79	15.97	35.78	14	38	25	68
1873	22.47	10.92	12.26	29.08	15	45	33	132
1874	8.12	3.75	4.74	17.73	11	2	16	5
1875	10.75	5.17	6.69	17.96	14	41	28	90
1876	34.20	17.21	20.95	45.78	13	40	30	100
1877	25.68	14.68	13.70	43.79	15	45	50	52
1878	26.45	7.83	20.39	39.10	16	42	48	67
1879	20.00	5.00	15.00	36.13	11	45	35	50
1880	21.03	5.32	16.21	29.11	11	32	24	73
1881	13.36	8.98	5.13	28.94	9	17	37	14
1882	20.71	9.70	11.68	28.35	22	50	45	80
1883	24.86	8.24	17.67	36.79	19	40	50	80
1884	23.43	10.22	15.57	33.62	23	47	41	110
1885	15.88	8.33	7.55	24.90	12	30	40	100
1886	19.96	11.18	10.33	28.85	16	25	35	75
1887	17.46	5.81	12.07	29.88	8	12	30	80
1888	17.73	6.11	14.10	31.29	19	29	36	20
1889	22.07	9.78	14.18	30.87	22	50	41	....
Average	20.50	8.78	13.01	31.55	15	35	36	65

[1] For the quarter ending December 31, 1889, p. 142.

Average yield and value of crops in good and bad seasons, Riley County, Kans.

Crop.	Average yield per acre.		Value per bushel, New York, 1890–1894.	Excess of good over average.		Excess of good over bad.	
	Good crops, 1882–1884.	Bad crops, 1874, 1881, 1887.		Amount.	Value.	Amount.	Value.
	Bushels.	*Bushels.*	*Cents.*	*Bushels.*		*Bushels.*	
Wheat	21	9	84	6	$5.04	12	$10.08
Corn	46	10	55	11	6.05	36	19.80
Oats	45	28	28	9	2.52	17	4.76
Potatoes	90	33	40	25	10.00	37	14.80

The years 1882 to 1884, inclusive, were very fruitful ones, and they show that with spring and summer rainfall amounting to from 22 to 25 inches in all, that country will yield 21 bushels of wheat per acre, 46 bushels of corn, 45 bushels of oats, and 90 bushels of potatoes, whereas the average crop for the eighteen years has been wheat 15, corn 35, oats 36, and potatoes 65 bushels. This is a striking illustration of the influence of rainfall in determining the yield of crops. It will be noticed that the total of the rainfall from April to August for these best years is about the same as the average for New Jersey, while the poorest years exhibit conditions quite similar to our own driest years. Thus we have in 1874, 8.12; in 1875, 10.75; in 1881, 13.36; and in 1887, 17.46 inches of rainfall, and in all these years most of the crops are very poor. If we compare the dry years in the table (p. 29) showing rainfall at different points in New Jersey we notice that the rainfall from April to August ranges from about 9.33 up to 17.79 inches, excepting in a few cases already pointed out, where the total from April to August does not fairly represent the severity of the drought. Taking the rainfall by seasons, the table (p. 31) shows a range for the driest season of the poor years of from 3.75 to 5.81 inches, while the table of New Jersey rainfall shows a range of from 4.62 to 8.62 inches. In general it will be seen, therefore, that while the average yearly rainfall of western Kansas is only about three-quarters of that of New Jersey, the rainfall during the growing months is quite similar to that of New Jersey both in its range and its average.

It appears that if during this period the crop could have been maintained as high as it was in 1882, 1883, 1884, and 1889, when rainfall was sufficient, the annual gain in crop per acre would have been 6 bushels of wheat, 11 bushels of corn, 9 bushels of oats, and 25 bushels of potatoes, which, at the value per bushel given, would have amounted to an average of $5.60 per acre on these four crops, or 34 per cent of the value of an average crop. It will further be found that the average loss on bad crops, due to light rainfall, amounts to $12.36, or 71 per cent of the value of an average crop. This is only offered as an illustration, for the probabilities are that irrigation would have produced still better crops than we have taken as the standard, because even when the rainfall as a whole is sufficient there will often be months or parts of

months in which the drought will be so severe as to injure the crop to a certain extent; besides, it is highly probable that irrigation in New Jersey will be applied to the raising of much more valuable crops than those above taken for illustration, and the gain for these crops will be at the same rate per cent as for the less valuable crops of our illustration. We may therefore, without attempting exact estimates of what the profit of irrigation will be where so much depends upon the character of the crop and the efficiency of treatment, safely consider that an outlay of $10 per acre per annum will afford a wide margin for profit in the hands of a good farmer. It is a well-known fact that the returns from irrigation have in very many cases been such as would give an ample profit on a cost of $10 per acre annually. The preceding tables make it appear, then, that there is a good promise of profit in such irrigation as will supply at all times in New Jersey moisture equal to that of an average year.

The following table shows the average rainfall and temperature over the four important divisions of the State:

Average rainfall and temperature of different sections of New Jersey.

Month or season.	Kittatinny Valley and highlands.		Red sandstone plain.		Clay and marl region.		Southern interior.	
	Rain.	Temperature.	Rain.	Temperature.	Rain.	Temperature.	Rain.	Temperature.
	Inches.	° *F.*	*Inches.*	° *F.*	*Inches.*	° *F.*	*Inches.*	° *F.*
January	3.48	25.3	3.63	28.5	3.73	29.5	3.83	30.5
February	3.31	27.7	3.45	31.0	3.55	32.2	3.64	33.5
March	3.57	33.8	3.72	36.8	3.82	38.0	3.93	39.3
April	3.48	47.2	3.63	49.4	3.73	50.6	3.83	50.7
May	3.88	58.8	4.04	60.3	4.16	60.9	4.27	61.5
June	3.88	67.6	4.04	69.6	4.16	70.1	4.27	70.6
July	4.05	71.3	4.23	74.3	4.35	74.6	4.46	75.0
August	4.42	68.6	4.59	71.3	4.71	71.9	4.84	72.6
September	3.57	61.7	3.72	64.5	3.82	65.1	3.93	65.7
October	3.33	50.1	3.45	53.6	3.55	53.8	3.64	54.1
November	3.57	40.4	3.72	43.4	3.82	44.0	3.93	44.7
December	3.57	29.8	3.72	32.5	3.82	33.3	3.93	34.1
Year	44.09	48.5	45.94	51.3	47.22	52.0	48.52	52.7
Spring	10.93	46.6	11.39	48.8	11.71	49.6	12.03	50.5
Summer	12.35	69.2	12.86	71.7	13.22	72.2	13.57	72.7
Autumn	10.47	50.7	10.89	53.8	11.19	54.3	11.50	54.8
Winter	10.36	27.6	10.80	30.7	11.10	31.7	11.40	32.7

This table makes clear the important bearing of temperature upon the relative dryness of these different sections. It is well known that droughts are felt in an increasing degree as we proceed from the Kittatinny Valley and highland region southward, but the table shows that the average rainfall increases in like manner, so that our driest section is the one having the largest average rainfall, and it has been fully established in the investigations of the run-off of streams[1] that evaporation increases about 5 per cent for each increase of 1 degree in mean temperature of the atmosphere. It will be seen from the table that between the Kittatinny Valley and highland regions and the southern

[1] Report on Water Supply, Geological Survey of New Jersey, 1894.

interior there is a difference of 4.2 degrees in the temperature for the year, which corresponds therefore to an increase of 21 per cent in the evaporation. This higher temperature fully accounts for the greater frequency of drought in southern New Jersey, and it is also seen in the table on page 29 and context that the greater average rainfall of that section is not accompanied by a greater rainfall during the driest seasons, which may be as dry here as elsewhere; consequently during such seasons the large increase of evaporation makes the drought more severe in this part of the State than farther north.[1]

The rain which falls upon the earth is partly dissipated by direct evaporation into the atmosphere; another part is taken up by vegetation, and practically all of the balance flows off in the streams. It is apparent, therefore, that if we have reliable measurements of the rain falling upon a given area, and of the amount flowing off in the streams during the same period, the difference between the two will represent the amount either evaporated or taken up by plants, most of which is ultimately also dissipated into the atmosphere, and may be included in the general term "evaporation." Our investigations show that evaporation is not directly proportional to the amount of rainfall, although it increases somewhat with increased rainfall. Formulas have been worked out[2] by which evaporation can be computed from the rainfall for each month of the year, the mean temperature of the locality being given. This enables us to determine just what amount of rainfall will be equivalent to the combined demands of evaporation and vegetation which we have included in the general term evaporation. The following table[3] gives the amounts for the different sections of the State :

Rainfall needed to be just equal to evaporation.

Season.	Kittatinny Valley and highlands.	Passaic watershed.	Red sandstone plain.	Southern New Jersey.
	Inches.	*Inches.*	*Inches.*	*Inches.*
Winter	0.97	1.10	1.16	1.27
Spring	3.19	3.70	3.91	4.31
Summer	9.46	11.12	11.97	13.37
Autumn	3.21	3.96	3.90	4.31
Year	16.83	19.61	20.94	23.26

Now, if rainfall should be just equal to the amounts given in the table, and we start with the ground full of water on April 1, the next table[4] shows how much water will drain out of the ground to the streams during the five growing months, the amounts being shown month by

[1] The reader is referred to Report on Water Supply, Geological Survey of New Jersey, 1894, and especially to pages 329 to 348, if he cares to pursue this line of study further than the present outlines.

[2] Report on Water Supply, Geological Survey of New Jersey, 1894, p. 180.

[3] Ibid., p. 336.

[4] Ibid., p. 340.

month in the first column, and the total to the end of the given month in the second column.

Flow from springs when rainfall equals evaporation.

Month.	Kattatinny Valley and highlands.		Passaic water-shed.		Red sandstone plain.		Southern interior.	
	Spring flow.	Depletion.	Spring flow.	Depletion.	Spring flow.	Depletion.	Spring flow.	Depletion.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
April	1.20	1.20	1.16	1.16	1.43	1.43	1.76	1.76
May	.55	1.75	.54	1.70	.64	2.07	1.38	3.14
June	.39	2.14	.40	2.10	.45	2.52	1.30	4.44
July	.32	2.46	.33	2.43	.35	2.87	1.02	5.46
August	.27	2.73	.32	2.75	.30	3.17	.63	6.09

The second column in each case shows the water held in the interstices of the soil. The removal of this from the soil is not necessarily harmful to vegetation, but, on the contrary, is, to a certain extent, necessary, and the farmer constructs underdrains in order to get rid of it to a depth of about 3 feet from the surface, the crops being supplied mainly by the water held in the soil by capillary attraction. The amount of water which may be held in the soil in this way, however, is dependent upon the depth of the free-ground water below the surface, by which we mean the level at which water will stand in an open pit from which no water is drawn. If this ground water recedes to too low a level, the power of the soil to hold water by capillary attraction is reduced.[1] Of course it must be remembered that the above conditions of rainfall are merely hypothetical, and they never actually occur, but, as will be seen by reference to the last two tables and to the tables of summer rainfall during the dry years which we have already given, the rainfall during summer very frequently falls below the amount needed to equal evaporation. In such cases there is a still further drying of the soil by evaporation which continues persistently in its work drawing from the ground water when rainfall is not sufficient to satisfy its demands. If, on the other hand, rainfall is greater than the amount shown nature compensates for the increase and prevents the drying out of vegetation by an increased amount of drainage from the soil into the streams; that is, the water in the soil and subsoil acts just like in a sponge, the more nearly the soil is saturated the larger the amount of water which will run from it. The condition of the ground water resulting from varied conditions of rainfall will be seen, therefore, to have an important effect upon vegetation and the growth of crops.

We may get an idea of how much the ground water may be drawn down on an average in different sections of the State without injury to vegetation from what happens during the average year. Our measure of the depletion of the ground water is, in each case, the depth of rain in inches needed to refill it. The greatest depletion during the growing

[1] U. S. Dept. Agr., Weather Bureau Bul. 5, p. 25.

months is shown[1] to be, for the different regions, as follows: Kittatinny Valley and highlands, 1.23; red sandstone plain, 2.26; clay and marl district, 3.78; southern interior, 4.66 inches. These are average figures. The actual amount of depletion ranges from practically nothing on the low grounds to nearly twice these amounts on the ridges. The next table shows month by month during the driest year likely to occur (1881), the amount run off in the streams, the rainfall, the excess or deficiency of rainfall, meaning by this the amount by which the rainfall exceeds or is less than the combined evaporation and run off of streams, and last, the total deficiency of the rainfall to the end of the given month, these last amounts representing the depth of rain in inches which would be necessary to refill the ground with water.

Rainfall, evaporation, run-off, and condition of ground water during driest year, measured in inches of rainfall.

KITTATINNY VALLEY AND HIGHLANDS.

	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Year.
Evaporation	0.74	0.57	0.69	0.76	0.83	2.13	3.07	2.91	2.58	1.61	1.10	0.76	17.75
Run-off	3.31	3.09	4.07	3.07	1.10	.60	.65	.27	.17	.14	.15	.20	16.82
Rainfall	4.05	3.66	4.76	3.83	.61	2.71	3.87	.96	1.18	.94	3.04	2.02	31.63
Surplus + or deficit −					−1.32	−.02	+.15	2.22	−1.57	−.81	+1.79	+1.06	−2.94
Total deficit to end of month					1.32	1.34	1.19	3.41	4.98	5.79	4.00	2.94	......

RED SANDSTONE PLAIN.

	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Year.
Evaporation	0.87	0.67	0.82	0.90	0.98	2.53	3.64	3.45	3.06	1.91	1.30	1.90	21.03
Run-off	3.18	2.99	3.94	2.93	1.30	.58	.47	.24	.16	.15	.16	.16	16.25
Rainfall	4.05	3.66	4.76	3.83	.61	2.71	3.87	.96	1.18	.94	3.01	2.02	31.63
Surplus + or deficit −					−1.67	−.40	−.24	−2.73	2.04	−1.12	1.59	+.96	−5.65
Total deficit to end of month					1.67	2.07	2.31	5.04	7.08	8.20	6.61	5.65	......

CLAY AND MARL DISTRICT AND SOUTHERN INTERIOR.

	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Year.
Evaporation	0.95	0.73	0.89	0.98	1.06	2.75	3.96	3.75	3.33	2.07	1.41	0.97	22.85
Run-off	3.10	2.93	3.87	2.85	1.46	.91	.84	.46	.30	.30	.30	.30	17.62
Rainfall	4.05	3.66	4.76	3.83	.61	2.71	3.87	.96	1.18	.94	3.04	2.02	31.63
Surplus + or deficit −					−1.91	−.93	−.93	−3.25	−2.45	−1.43	1.33	+ .75	−8.84
Total deficit to end of month					1.91	2.86	3.79	7.04	9.49	10.92	9.59	8.84	......

NOTE. The quantities representing the total deficit at the end of a given month show how much rain or water of irrigation would be needed to refill the ground.

It will be noticed that the run-off of the streams is greater for the southern than for the northern sections of the State, the reason for this being that the soil is sandy or gravelly and contains more water in a given volume than the closer soils of the northern portion of the State, and also gives up the water more freely to the streams. We have

[1] Report on Water Supply, Geological Survey of New Jersey, 1894, p. 341.

selected in each case the best type of each section, but it must be remembered that there are minor differences for different parts of the given section—that is, parts of the Kittatinny Valley and highlands which have a large amount of sand and gravel over their surface will also show a larger run-off into the streams, and a greater lowering of ground water than is shown by the table. It will also be noticed that, while the rainfall is taken to be the same for all parts of the State, evaporation increases for the different sections because of increased temperature, and the combined effect of greater evaporation and greater drainage into the streams is a very much greater lowering of the ground water in the southern portions of the State, and this affords a still better explanation of the greater severity of droughts in those portions of the State.

The inspection of the table shows that by the end of August the following amounts of rain would be needed in this driest year to refill the ground water: Kittatinny Valley and the highlands 4.98, red sandstone plain 7.08, and clay and marl district and southern interior 9.49 inches.

It is believed to be due, to a considerable extent, to this greater lowering of the ground water that sandy and gravelly soil such as that of southern New Jersey is warmer than more retentive soils. Many phenomena connected with the growth of crops are explained by this tracing of the conditions of rainfall, evaporation, drainage to streams, and height of the ground water for different sections. An important fact to be kept in view is that the result of irrigation is to hold the level of the ground water at a more nearly constant height, and in consequence of this there will be a somewhat increased discharge of water from the subsoil to the streams. We have, consequently, to supply not merely the water demanded by the plants but this additional run-off from the soil. This increased porosity of sandy soils and readier discharge therefrom is not, however, to be regarded as an unfavorable condition to irrigation. On the contrary, it insures good drainage and prevents the presence of stagnant water in the ground in case of excessive watering, which is sometimes so hurtful to irrigated crops.

AMOUNT OF WATER NECESSARY.

Knowing that our average rainfall represents conditions very favorable to good crops, this affords a simple standard by which we can determine how much water will be necessary for irrigation in the various sections of the State, for we may safely assume that it will be the difference between the average for each section, and the lowest rainfall for the various periods as shown by table, page 29. In this table we find the lowest amount of rain from April to August is 9.33 inches, and by seasons the lowest for the spring is 5.23 inches, and for the summer, 4.62 inches. For the driest month the rainfall is only a fraction of an inch, and we may safely assume that we will have to provide

a quantity equal to 4 inches of rainfall for at least one month during certain years. This gives us the following estimate of water required:

Quantity of water required for irrigation measured in inches of rainfall.

	Driest April to August.	Driest summer.	Driest month.
Kittatinny Valley and highlands	10.42	7.73	4.00
Red sandstone plain	11.20	8.24	4.00
Clay and marl regions	11.78	8.60	4.00
Southern interior	12.34	8.95	4.00

We find, therefore, that for the whole growing season we shall have to provide in southern New Jersey practically the equivalent of 12 inches in depth of rainfall, and that our works must be so proportioned as to be able to deliver during one month the equivalent of 4 inches. The latter may be taken as the required capacity of the canals and ditches or other means of conveying the water, while the quantities in the first column represent the total amount of water which must be provided. For very much of the time this will be more than is actually needed, but irrigation works, to be satisfactory and successful, should be capable of meeting the driest possible conditions. At 4 inches per month the duty of water, as it is called, or the required rate at which the water must be furnished, is 0.55 cubic foot per second for each hundred acres. As it has been found in California, with a temperature considerably higher than that of New Jersey and a lighter rainfall, that the requirements are met by 1 cubic foot per second for each 200 acres, which is very close to the above estimate, this may be adopted as the proper average duty for southern New Jersey. We have found that the streams of southern New Jersey may be depended upon in the driest month to discharge 0.25 cubic foot per second for each square mile of catchment, and it follows that without storing water we may draw from these streams enough water to irrigate 50 acres of land for each square mile of gathering ground on the stream.

STORAGE OF WATER.

In cases where it is practicable to construct storage reservoirs to utilize the yield of the stream during the wet season for irrigation purposes a much larger area can be watered by a given stream. Our investigations in southern New Jersey show that we can always utilize 12 inches of rainfall, even in the driest year, but in order to make this amount available during the growing months from April to August we shall have to provide storage at the rate of 122,000,000 gallons for each square mile of catchment. As we need just 12 inches depth of water for irrigation purposes, it follows that with this amount of storage a stream would furnish enough water to irrigate an area equal to its catchment. The cost of storing water varies considerably with the locality, and is great for small amounts and less for works on a

large scale, but for our present purposes we may take the cost to be $150 per million gallons, making the cost of the above 122,000,000 gallons $18,300, a charge on 640 acres amounting to $28.60 per acre, which is evidently too high a cost for storage alone. To utilize 6 inches of rainfall on the catchment, we shall need 36,000,000 gallons storage for each square mile, costing $5,400, and this would serve to irrigate one-half a square mile, or 320 acres, making the cost $16.88 per acre for storage. To utilize 3 inches of rainfall on the catchment during the growing months, we shall need 17,000,000 gallons of storage for each square mile of catchment, costing $2,550, and this would irrigate 160 acres, making the cost about $16 per acre, and it will be seen that we must be prepared to expend about this amount if storage is attempted at all. The question must be decided however, for each case; consequently in making up our estimates of the ultimate capacity of various streams for irrigation purposes we have taken an area equal to the catchment of the stream.

SEEPAGE, OR RETURN WATER.

We have already seen that a considerable part of the rainfall flows off in streams, and in our table of flow from springs we find that without any additions from rainfall the soil will yield up as seepage, during the five growing months, a quantity of water equal to from 2¾ to 6 inches of rainfall in various parts of the State, the latter amount being that given up by the sandy soils of southern New Jersey. The rate at which this water is discharged depends on the amount held in the soil or the height at which the ground water is maintained, as shown by the table. Since the purpose of irrigation is to maintain ground water at a higher elevation than it would otherwise stand, it follows that the amount of this seepage or yield from springs to the streams would be increased thereby. During the average year we find[1] that the ground water is drawn upon or depleted from April to August, an average of 2.32 inches on the coast streams of southern New Jersey, whereas during the driest year it is depleted to an average of 5.82 inches. Now, if we assume that by irrigation the ground water will be maintained in the condition of an average year, the flow of seepage or spring water will be increased from that due to 5.82 inches depletion to the amount due to only 2.32 inches depletion. It has been shown[2] for the Great Egg Harbor and Batsto catchments that for any given depletion 2.32 inches depletion corresponds to a yield of 1.40 inches per month and 5.82 inches depletion to a yield of 0.8 inch per month. Therefore we have an excess amounting to 0.6 inch per month of seepage water due to irrigation on this assumption. We may check this by taking into account the yield of these southern streams for the average and the driest year.[3] From April to

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[1] Report on Water Supply, Geological Survey of New Jersey, 1894, p. 341.
[2] Ibid., p. 126.
[3] Ibid., p. 266.

August this yield amounts to 8.37 inches for the average and 5 inches for the driest year, showing an excess for the average year of 3.37 inches during the five months, or 0.67 inch per month, agreeing sufficiently well with our previous estimate. It therefore appears that if we used for irrigation an amount of water equal to 12 inches of rainfall, 3 inches will be returned as seepage water, or 25 per cent of the total amount diverted from the stream. This estimate, arrived at from observations of the yield of the streams, agrees well with results obtained by some actual gauging of streams in irrigated sections of Colorado.[1]

The actual amount of seepage or return water will probably exceed this estimate somewhat, from the fact that ground water will be usually held at a little higher level, but we are disposed to think that very much increase in height would be rather detrimental to crops than otherwise. There is a tendency, where irrigation is applied, to use too much water. As we have previously stated, the drawing down of ground water to a certain extent is necessary for the proper development and perfection of the crop. Good drainage is very essential to successful irrigation. The presence of free ground water about the roots of plants prevents the proper irrigation and consequent oxidation of the elements of the soil necessary for plant growth, and it also produces a cold and late soil.

The amount of this seepage or return water should have an important bearing on the question of damages for the diversion of water in all cases where such seepage water returns to the stream from which the irrigation water has been diverted. It will almost invariably return to the same stream when the irrigated district lies within the catchment of that stream.

COST OF IRRIGATION.

The following figures given by F. H. Newell[2], pertain to the western part of the United States, where irrigation is successfully practiced.

Cost of irrigation in the western United States.

	Average for United States, per acre.	Average for California, per acre.	Average for Utah, per acre.
Cost of irrigation works	\$8.15	\$12.95	\$10.55
Value of water rights	26.00	39.28	26.84
Annual cost	1.07	1.60	.91
Cost of bringing land under cultivation	12.12	17.48	14.85

The first figures given above represent the cost of bringing the water to the land, while the next below represent the value of such water after it has been secured, and subtracting the first from the second we

[1] Colorado Sta. Bul. 33.

[2] Report on Agriculture by Irrigation in the western part of the United States, Eleventh Census, p. 8.

find an average profit by irrigation of $17.85 per acre from enhanced value of land taken together with the water rights. The annual cost is either that of maintaining the works, or is the annual rental paid for the use of water when furnished by a corporation, while the cost of bringing land under cultivation includes clearing and leveling up to receive water. In California irrigation is applied to orchards, vineyards, small fruits, and other more valuable crops, so that the figures for that State are a better guide to us in New Jersey than the average of the whole. In the table, page 32, we showed that irrigation might easily yield an improvement of about $10 per acre in the potato crop, but we should here remark that of late years the hay crop in New Jersey has been a valuable one, and the very moderate improvement of 1 ton per acre in this crop would yield a larger return than $10 annually. Indeed, the raising of hay and forage crops by this means would be of great advantage to portions of southern New Jersey, where they are now grown with much difficulty. Taking 6 per cent on the above figures of first cost of works for California, we have for interest 78 cents, which added to the annual cost makes $2.38 annual charge per acre, to which we must add the extra labor of applying the water, or of irrigation farming over dry farming. The latter cost will depend largely on the crop, but may be averaged at about $6 a season, making a total increased cost chargeable to irrigation of $8.38 on the California basis.

As the conditions in southern New Jersey are generally favorable to low cost of irrigation by means of canals and ditches, on account of the character of the soil and the gentle and uniform slopes, there is no reason why the average cost should exceed the above estimate, and in many favorable localities it will be considerably less. Where there are valuable water powers this will add appreciably to the cost of irrigation and will make it almost impossible to carry out a profitable scheme, except it be done on a large scale. For illustration, if Maurice River should be fully utilized for irrigation it would water, without storage, 19,300 acres, and with storage about 250,000 acres. The cost of extinguishing the rights of water-power owners would probably amount to not less than $20 per acre on the smaller area and about $1.50 per acre on the larger area. This difficulty would generally be much less serious than in this case. however, although it would frequently be encountered. It must be remembered, in considering this question, that we are very conservative in our estimates as to the area which may be watered by these streams, from the fact that we have thought it well for the present not to take in consideration the large amount of the seepage water returned to the stream. Those who have followed our discussion of the irrigation water required by soils have observed that a considerable part of it is needed to make good the flow from springs which drain the water out of the soil. This water, of course, returns to the streams, and may be used over again, although we have not taken it into account.

AREAS CAPABLE OF BEING WATERED BY GRAVITY.

The following areas in southern New Jersey are capable of being brought under water and supplied by gravity through ditches and canals:

Metedeconk River in Ocean County is capable of watering 3,700 acres without and 47,000 acres with storage. All of this land, favorably located and having a soil well adapted to the purpose, may be found to the south and east of Burrsville. The water rights interfered with in this case would not be so important as to be a serious obstacle.

Toms River in Ocean County would water 8,200 acres without and 105,000 acres with storage. This water could be applied to various strips of land along the stream and its branches, although, on the whole, the topographical conditions are less favorable than on the Metedeconk.

The waters of Cedar Creek and Forked River will suffice to irrigate 3,500 acres without and 45,000 acres with storage. They could be applied to good lands in sufficient amount and favorably located between Waretown and Barnegat Park along the bay shore. Mill Creek, West Creek, and Tuckerton Creek, in Ocean and Burlington counties, will water 2,500 acres without and 32,600 acres with storage. These also could be used on good lands favorably situated near Manahawken, West Creek, and Tuckerton. Wading River is capable of watering 9,000 acres without and 115,000 acres with storage. Lands well adapted for the purpose are found about New Gretna, Harrisville, and Green Bank, with some smaller areas along the upper stream and its branches.

Mullica River above Batsto will furnish sufficient water to irrigate 11,000 acres without and 140,000 acres with storage. The watershed of this stream is almost level in a direction almost transverse to the course of the streams, and slopes with the streams at the rate of about 5 feet to the mile. A large area of sandy land could easily be brought under water lying between Batsto, Hammonton, and Atsion. This land is at present mainly waste land.

Great Egg Harbor River will furnish water for 15,000 acres without and 192,000 acres with storage. The water could be used on a belt of land along the stream between New Germany and Mays Landing, most of which is wild land; also on a strip along each bank below Mays Landing, that along the west bank between the highway from Mays Landing to Tuckahoe and the salt marsh being quite favorable for the purpose, and including some areas now under cultivation. An important water power at Mays Landing would be affected by any extensive irrigation works, but along the west bank between Mays Landing and Tuckahoe considerable development could be made by utilizing South River and Stephens Creek without affecting any valuable water power. The same is true of Babcocks Creek at Mays Landing.

Tuckahoe River is sufficient to water 2,500 acres without and 32,000 acres with storage, and land well adapted for the purpose, a consider-

able part being already under cultivation, is found along both banks of the river between Hunters Mill and Tuckahoe.

The streams of Cape May County are not adapted for gravity irrigation except in a limited way. Manumuskin and Manantico creeks would together furnish water for 3,500 acres without and 44,000 acres with storage. They could easily be made to water all of the land between the West Jersey Railroad and Maurice River, extending from Millville to Port Elizabeth, and Manantico Creek, especially, affords an opportunity for an irrigation development on a considerable scale without interfering with any water rights, all the mills on the stream being now abandoned.

Maurice River above Mays Landing is capable of watering about 11,000 acres without and 170,000 acres with storage. The water would have to be applied to lands lying along both banks of the river and its branches, and generally not more than 30 feet higher than the stream. Not much of this land is now under cultivation, although there is some on the west branch between Union Grove and Bradway.

On the Atlantic coast of southern New Jersey the above-mentioned streams offer good facilities for irrigation by gravity, but the streams on the Delaware slope of the State do not present such favorable topographical conditions. For the most part these streams run at low level through ravines with flat bottoms and rather steep banks, so that the water could only be brought out on the neighboring lands by means of low canals from points so high on the streams that the drainage area is small and insufficient to furnish any large amount of water. This country along the lower Delaware, however, contains some fertile lands, and it is the region of the lightest rainfall and severest droughts in the State; consequently it is probable that nowhere else would irrigation be more profitable.

Cohansey Creek above Bridgeton would water 2,250 acres without and 28,000 acres with storage, but the topographical conditions are very unfavorable for gravity systems. We shall see later how the waters of this creek may be used advantageously by pumping. Salem Creek, at Sharptown, if diverted at about 50 feet elevation, could be made to water 1,000 acres without and 14,000 acres with storage. This water could be used profitably on fertile lands now under cultivation in Upper Penns Neck and the west part of Mannington Township.

Alloways, Oldmans, Raccoon, Timber, and Coopers creeks are open to the objections which we have pointed out as peculiar to streams of the Delaware slope, and are not well adapted for gravity systems of irrigation.

Rancocas Creek above the forks will water 15,000 acres without and 192.000 acres with storage, but there is a considerable amount of valuable water power which would be affected. The water could be applied to land distributed along the stream in Pemberton, Lumberton, East Hampton, and South Hampton townships, Burlington County, most of these lands being now under cultivation.

Crosswicks Creek is not well adapted to a gravity system of irrigation.

Some 5,000 acres of level gravelly lands east and northeast of Trenton, and under 60 feet elevation, could be watered by the head waters of Assanpink Creek.

This brief review of the possibilities of gravity irrigation in southern New Jersey shows us that 75,000 acres can readily be watered without the use of storage reservoirs, and over 900,000 acres if the streams are fully utilized by storage. We have seen, however, that the cost of such storage would scarcely be warranted, but we may consider that the watering of 250,000 acres of the areas which we have indicated is entirely practicable. Most of this land is on the Atlantic Slope, and very little of it is now under cultivation. Exclusive of storage charges, it could generally be irrigated at a cost within the figures already given for California, or, say, within an annual charge of $8 per acre. If this area could be successfully brought under cultivation by this means it would add 10 per cent to the total cultivated area of the State, and probably from 20 to 25 per cent to the value of its agricultural products. Several of the districts mentioned offer excellent opportunities for a beginning on comparatively a small scale, and in such a manner that ultimately the development could be extended to the full capacity of the stream. We must recognize the fact that the benefits to be derived from irrigation must first be demonstrated by works on a limited scale, although the highest efficiency and the largest amount of profit will be realized by a large scale of development. Generally the soil of these tracts, and the configuration of the surface are very favorable to the purpose, and a large part of the land could be acquired at a low cost. The conditions are peculiarly favorable for market gardening and the raising of fruit.

In the northern part of the State the need of irrigation is sometimes felt quite severely on the red sandstone plain, but to a much less extent in the Kittatinny Valley and highlands. The water could almost always be applied on this part of the State by gravity, but water rights are more valuable here, so that it is scarcely probable that irrigation will be extensively adopted for general farming, although it may be for special crops.

We shall not undertake for the present to extend our mention of these specific cases suitable for gravity systems of irrigation into northern New Jersey. There are, however, quite a number of cases where irrigation could be used profitably in these portions of the State. Considerable areas, such as Pompton Plains and other fertile portions of the Passaic Valley offer facilities for such improvement.

IRRIGATION BY PUMPING.

While irrigation by gravity through canals and ditches is a simple and well tried method and one which usually gives a low operating cost,

there are many cases in New Jersey where the water could be advantageously pumped. There are large fertile areas in Salem and Gloucester counties which can not be watered by gravity, but which are traversed by numerous creeks, where an abundant supply of water can be obtained at all times. The whole area is also bordered by the Delaware River, the water of which, down to the head of the bay, is usually fresh enough to be used for this purpose. A considerable area of good land along the east shore of Delaware Bay and south of Cohansey Creek is similarly situated. Then, again, in many cases the cost of extinguishing water rights would be eliminated by pumping from the lower parts of the streams, and the saving thus effected might fully compensate for the cost of pumping, not to speak of the saving in construction of long main canals. Pumping could be applied in the districts which we have mentioned, either to raise the water into canals and ditches, to be distributed by the ordinary method, in which case pumping would be done inexpensively by centrifugal pumps; or force pumps could be used and the water distributed under pressure through a network of pipes to be laid over the district to be irrigated, the water being applied by means of hose from a number of conveniently situated hose plugs. At first sight this seems an expensive method, but it bears the test of careful estimate, and has very great advantages where it is important to economize water or to distribute it readily and conveniently, as would be the case where irrigation is employed in market gardening and in orchards. We have taken for the purpose of an estimate an area of 640 acres, or, say, 32 garden plats of 20 acres each, the water being pumped from a stream and distributed by means of pipes, as we have suggested. We find that for such a tract of land a plant of the best character could be installed for $45,000, or about $70 per acre. We also estimate that, allowing on this sum 6 per cent interest and 3 per cent for depreciations, all expenses of operation, including the watering during a season of one hundred days, would not exceed $15 per acre. We believe that good returns could be had from this outlay in any of the districts which we have mentioned as favorable to the application of this system. The cost of this system per acre would increase with smaller plats than 640 acres, and would decrease if applied on a larger scale. It is probable, however, that by the use of small pumps operated by gasoline engines, which could be operated without the constant attendance of an engineer, the system could be profitably applied without much increase of cost to a single ordinary farm. For smaller plants, however, such as are likely to be adopted experimentally during the early attempts at irrigation in the State, it is probable that a windmill pumping to a tank, either from a well or stream, the water to be distributed from the tank by pipes, would be the most practicable system.

We shall leave the consideration of this question of limited or experimental plants for consideration in a later paragraph (p. 48).

AREAS ADAPTED TO IRRIGATION BY PUMPING.

The following areas are conspicuously adapted for such an extended system of irrigation by pumping as we have estimated upon, while they are not favorably situated to be watered by gravity. In Cumberland County, south of Cohansey Creek and west of the Cumberland and Maurice River Railroad, near Fairton and Cedarville, some 16,000 acres could be thus irrigated. The water for this purpose could be obtained from Cohansey Creek. The soil is good, and most of this district is now under cultivation. Some 500 or 600 acres between Cohansey and Stow creeks in the same county could be watered partially by pumping and partially by gravity. The whole of the western portion of Salem County, extending 6 miles or more back from the Delaware River and including some 80,000 acres of fertile land, most of which is now under cultivation, is well adapted for irrigation by this method. In Gloucester County about 40,000 acres along the Delaware and its branches could be watered. In Camden County about 12,000 acres, and in Burlington County 25,000 acres are suitable for this treatment. There is also some land between Red Bank and Colts Neck, in Monmouth County, which could be watered from Swimming River. A total of at least 175,000 acres of good land, mostly under cultivation, in the counties named, is adapted for irrigation by pumping either into irrigation canals in the more usual way, or into pressure pipes, as we have suggested. Most of this land lies convenient to tidal creeks and rivers whose waters are fresh or only slightly brackish. The waters of many of these creeks also carry a very considerable amount of rich sediment, and would undoubtedly have a marked fertilizing tendency.

IRRIGATION BY WELLS.

As is now well known, southern New Jersey affords an excellent field for obtaining water supply from tube wells. An examination of a considerable number of wells indicates that it is fair to expect from a 6-inch well, from 100 to 200 feet deep, a yield of 25,000 gallons daily, or sufficient to irrigate 10 acres of land. This is purposely conservative, and we are well aware that there are a number of wells which would be ample for 20 acres. Of course this method of irrigation means that we must pump by windmill or other power, and in order to use the water economically it should be applied by pipe distribution under pressure. This well water may have the disadvantage of a lower temperature, which could be partially remedied by storing in a tank, and may not have all the fertilizing properties of stream water, but the method allows the entire plant to be confined to the limits of a small farm without risk of damage to water rights or otherwise. There are also many cases where a number of small driven wells of moderate depth, say 15 or 20 feet, would answer the purpose better than tube wells. It is impossible to make any estimate of how much land may be irrigated in this way, but the aggregate may be large.

WARPING.

This process, which properly comes under the head of irrigation, is applicable to tidal meadows which have been reclaimed, and is a process not unknown in Cumberland and Salem counties, where it has been practiced to a certain extent for many years. It is a well-known fact that tidal meadows which have been embanked and improved generally shrink or settle to a level considerably below the level of high tide. Some of the older embanked meadows in the State range from 2 to 4½ feet lower than high-tide level. This gives an opportunity for the application of warping, which consists in letting the water flow in upon the embanked land to deposit its sediment. The system has been carried to a high degree of perfection in some portions of England, where the works are of a substantial character and the water is controlled by permanent sluices. In our own State the process is often effected by simply cutting the banks, which does not leave the farmer a proper control of the water. The purpose to be kept in view in this method of irrigation is to secure the best and largest part of the sediment contained in the water as a deposit upon the land, and the flowing and running off of the water must be so controlled that the volume of mud deposit has an opportunity to dry between tides. The result, when properly conducted, is to secure to the land under treatment a new soil, and the accumulation of sediment is much more rapid than would commonly be supposed. Ordinarily one year will suffice to entirely renew the soil of such a tract. The area of tidal meadow which has been reclaimed in Gloucester, Salem, and Cumberland counties amounts to about 26,000 acres. In the past the cultivation of these tracts has been very profitable, but during recent years there has been a tendency to neglect them somewhat, a fact which is partly due to the low prices of agricultural products; but while the very large returns of the past may not be again obtained, it is worth while to consider whether, even under present conditions, a good profit is not possible in cultivating these meadows, and whether a careful application of the warping process would not be a means to this end.

WATER MEADOWS.

While the application of irrigation will probably be most sought by the market gardeners and producers of small fruits, it seems worth while, in view of the general scarcity of hay and pasturage in southern New Jersey, to call attention to the possibilities of irrigation in producing hay and forage crops. The application of irrigation to water meadows in England is well known, and the results seem to have been highly satisfactory. The method of applying the water does not differ materially from ditch and bed work irrigation for other purposes, but the water is mainly applied through the winter months in England, although to a less extent throughout the year. It is so applied as to

protect the grass from the effects of early and late frosts, thus giving it an opportunity to start much earlier in the spring. It has been found possible to produce on each acre one month's grazing for from thirty to forty head of sheep in the spring, and after that 2 or more tons of hay has been cut, or when used for grazing alone the same number of sheep has been fed throughout the season. This is sufficient indication of the possibilities of irrigation for this purpose, and there seems no good reason to doubt that on the low-lying lands of southern New Jersey as good results as this could be obtained. The expense of watering such meadows is comparatively light, but the amount of water used is rather large. However, since the water is used largely during the months when it is not employed for irrigating ordinary crops the large amount needed would not be any great objection, and the irrigation of meadows could well form a part of a general system of irrigation.

TOTAL AREA IRRIGABLE.

If we consider only the available water supply, we find that even in the driest year which we have experienced enough water has run to waste in the streams to furnish an ample supply to irrigate the entire area of the State. Considering only the areas in southern New Jersey which we have pointed out as peculiarly well adapted to development at a reasonable cost, we find that, neglecting what may be watered by wells, fully 325,000 acres may be brought under water, and this alone, if well managed, would probably increase the value of the agricultural products of the State not less than 30 per cent.

ESTIMATED COST OF IRRIGATION AND SUGGESTIONS FOR SMALL PLANTS.

Our estimate of duty of 1 cubic foot per second for each 200 acres amounts to 3,236 gallons daily per acre during the month of maximum requirement. With a pipe distribution the economy of water would be such that this would probably be reduced to 2,500 gallons daily per acre. Our maximum monthly requirement was estimated at 4 inches per month, and if we assume that by pipe distribution this may be reduced to 3 inches, and let this be divided into four waterings, we shall need three-fourths of an inch for each watering, or practically 20,000 gallons per acre. Let us assume that we wish to water an area of 10 acres requiring 200,000 gallons for each watering. We estimate in all sixteen waterings for the season, and for the driest month we shall need one watering each week. If we apply this water in six days, we shall need all of the time of one man during this month, and ninety-six days of his time during the season of maximum requirement. If we arrange our plant so that the watering may be accomplished in three days, the driest season will require forty-eight days in all for the watering and 66,000 gallons daily. This is probably a good basis on which to work, because there will be many years when only a fraction of this amount

of time will be consumed, and, indeed, the maximum requirement will only occur at long intervals. At ten hours daily we must be able to distribute 6,600 gallons hourly from any hose plug in the plant, and this determines the capacity of our pipes and pumping engines.

It is evident that for a plant of this size, if we must depend on windmills, we should have tanks at hand to store at least one day's requirement, or 66,000 gallons. Assuming that our 10 acres is square, with a well driven at the center, and pumping by windmills to tanks, we estimate that the entire cost of installing the plant will be $4,500, or about $450 per acre. Of course, the operating expenses of such a plant will be light, as nothing is required for fuel and the operation of the pumps. This provides for an ample plant, but if one chooses to take some chances on the extreme dry years a lighter plant will suffice, and the cost may be cut down even as low as $2,500 and still give works of fair efficiency, which may once in twenty-five years during an extremely dry season require all of one man's time to do the watering. In this plant we have adopted 4-inch galvanized, lap-welded wrought-iron pipe for the distribution, and so disposed that the maximum distance from a hose plug to any part of the tract is 110 feet. About 100 feet of 2-inch hose would consequently be required.

If we substitute for the windmill a gasoline vapor engine of sufficient capacity to deliver 6,600 gallons hourly, we may do away with the storage tanks, provided that our well is of sufficient capacity to yield this amount of water. Of course, this will deliver the water at a lower temperature. The cost of such a plant will be about $1,000 less, or $3,500. This would probably also be reduced to $2,500 by adopting a lighter plant, say one capable of delivering 3,300 gallons hourly. Such a plant would have 3-inch pipe instead of 4-inch, as well as a lighter engine, and since during the driest weather its deficiency could be made good by simply taking more time to do the watering it is probable that this reduction would be a wise economy. In case this plant should draw from a stream instead of a well the cost would not be materially different in case the stream was not more distant than about 500 feet from the tract to be watered. The gasoline engine is to be preferred to the windmill because of its greater reliability. The cost of operation is light, as the engine needs very little attendance, the cost of fuel for the lighter engine amounting to about 50 cents daily.

There are also probably a number of localities near some existing or abandoned mill site where water power could be utilized cheaply for pumping, thus offering favorable conditions for a test of irrigation.

If we wish to adopt a gravity system for our test it will usually be advisable to construct works sufficient to bring about 100 acres under water, and even to do this it will generally be economy to select a site favorable to further extension and begin our works on a plan adapted to such extension. Thus a ditch 7 feet wide on top, 2 feet at bottom, and 2½ feet deep can be constructed in many parts of southern New

Jersey at a cost not exceeding 12 cents per foot. Such a ditch with a fall of 1 foot in 2,500 will deliver 20 cubic feet a second, or enough water to supply 4,000 acres of land. If a favorable location is selected, either where there already exists an abandoned milldam which can be repaired or where the site is favorable to a small dam at low cost, a mile of canal and a dam may be constructed at a cost not exceeding $1,100, and 100 acres could be brought under water. The cost would, therefore, be $11 per acre, which is not excessive. This will enable a thoroughly satisfactory trial to be made, and such works could be gradually extended until the entire cost for dam, canals, and main ditches would not exceed about $5 per acre. The economy of large-scale works by the gravity system is very marked, but it will be seen that if a start is made under such conditions as we have supposed the cost of a small development need not be excessive, while if successful the prospects are excellent for a large profit in the ultimate extension of the works. Newell's figures (p. 40) show that, taking the average over the whole United States, the rental value of this water thus brought to the land would amount to $1.07 per acre, while in California it amounts to $1.60. Many instances might be quoted where a much higher rental has been paid, but these figures are sufficient to suggest the handsome return possible from such a plant. It is impossible for us to enumerate at present all the points at which such a development could be reached under favorable conditions, but among others we have in mind Hunter's mill pond, to be used for the lands along the north bank of the Tuckahoe River; Cumberland Pond on Manumuskin Creek, to be applied along the west bank of the creek; the pond at Bamber and Cedar creeks in Ocean County; the mill pond on Kettle Creek at Silverton, where there is probably not more than enough water, however, for about 400 acres. Conditions are generally less favorable for such a plant on the Delaware slope, for reasons which we have already pointed out. Still they may be found on examination.

USE OF IRRIGATION IN NEW JERSEY—METHODS AND RESULTS.

More or less complete data on the above points were secured from five irrigation plants, three located in Gloucester, one in Cumberland, and one in Hunterdon County. Three of these have been in operation from two to twelve years, have given eminent satisfaction, and illustrate the practicability and usefulness of irrigation for small fruits and vegetables, especially on limited areas.

IRRIGATION ON THE FARM OF JOHN REPP, GLASSBORO, GLOUCESTER COUNTY.

Mr. Repp's fruit farm of 100 acres is located near Glassboro, Gloucester County, upon which is grown a great variety of fruit, peaches, apples, berries, grapes, etc., while a considerable portion of the land is devoted to market gardening while being prepared for fruit crops. Mr. Repp irrigated from 2½ to 3 acres since 1884, and is about to increase largely his operations in this direction. He has found that during two

years out of three there will be dry spells, when it will pay to irrigate the crops with which he has experimented.

Character of soil and method of manuring.—The land that has been irrigated during the last twelve years by Mr. Repp is a sandy loam underlaid by a clayey subsoil. It had been heavily manured with New York stable manure and fertilizers before being irrigated, and has been manured every year since 1884 in the same way until 1892. Since 1892 chemical fertilizers have been used alone before planting. He still uses the manure in the fall as a mulch.

The irrigation plant.—The accompanying outline shows the position of the land, 5½ acres, upon which irrigation has been practiced and the location of the reservoir, pump, and pipes in reference thereto.

A shows the shape of the pond, which covers about one-half an acre.

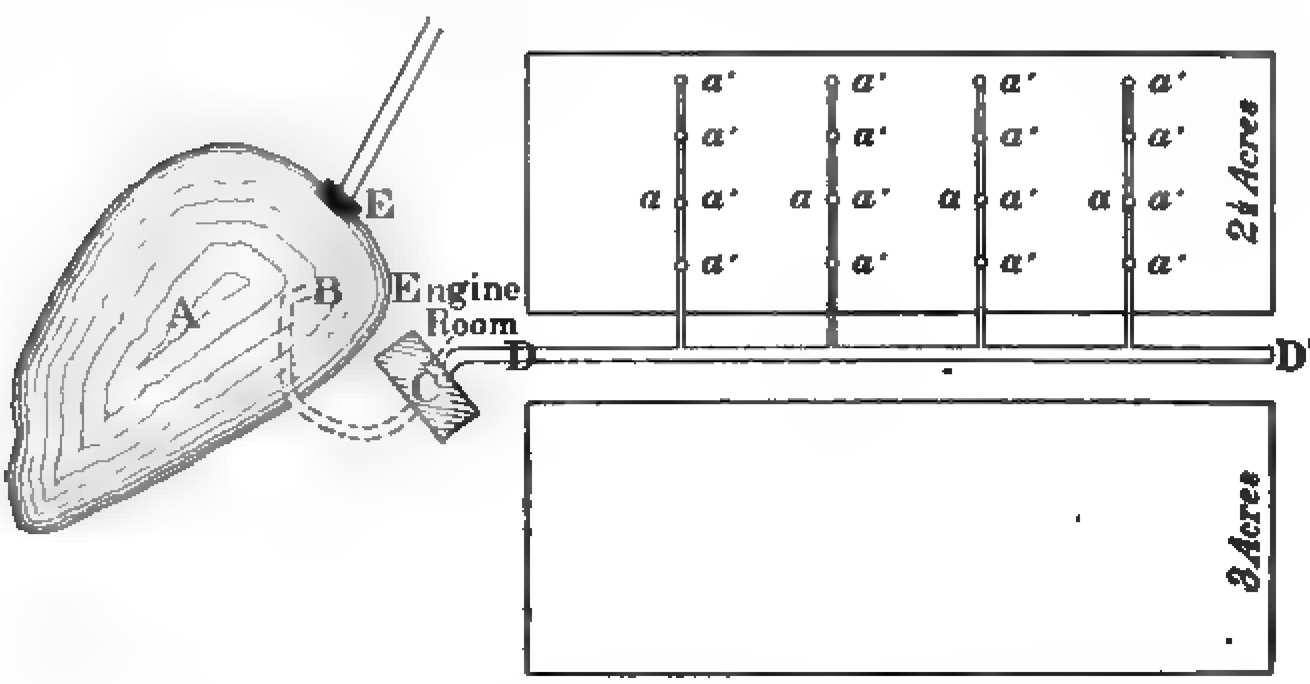


FIG. 3.—Irrigation system on the farm of John Repp, Glassboro, N. J.

The water backs up into the swampy land where the springs are located, and is about 4 feet deep near the dam.

The pipe that carries the water to the pump opens near the surface of the pond, several feet from the bank. The water enters the pipe through a strainer.

C represents the position of the engine house, or pumping station. This is a small, substantial structure, built to cover and protect the steam pump and boiler, which fill the available space therein.

At D D′ is shown the position of the underground main pipe, 1½ inches inside diameter, leading from the pump to the field to be irrigated, which is divided into two nearly equal parts by this main pipe. On one side is 3 acres, on the other 2½ acres. The side pipes *a a a a*, ¾ inch inside diameter, are laid under ground at distances of 10 feet. These pipes are furnished with faucets *a′ a′ a′ a′* for attaching rubber hose.

Irrigation of strawberries.—Mr. Repp describes his actual operations in watering or irrigating a field of strawberries as follows:

About ten years ago I built a dam across a small stream, fed by springs, that runs through my place, and inclosed about one-half an acre of water, 3 to 4 feet deep.

The land I wanted to irrigate is from 4 to 10 feet above the water. I first thought I would get a windmill and pump the water into a reservoir, but I found it would take 800 barrels of water to cover 1 acre an inch deep, and as I wanted to grow about 3 acres, in time of drought it would be necessary to put on not less than 1 inch of water twice a week, thus, in my judgment, rendering the storage scheme too expensive; so I put in a steam pump which, with an 8-horsepower boiler, will raise 800 to 1,000 barrels a day. The cost of the entire plant, including pipe and hose, was $600.

I laid off my land in two blocks, 2½ acres in one and 3 acres in the other. Between the blocks I laid a 1½-inch pipe under the ground. I have one of the blocks in berries each year. In planting, get ground fine and level, mark out with hand marker every other row 20 inches, every other 28 inches, plant 1 foot in row, cultivate and hoe. In hoeing, the man walks in the wide row; by so doing leaves the ground a little lower between the narrow rows. In August stop cultivating between the narrow rows, let them fill up with runners, and keep the wide rows cultivated till fall. Before winter sets in cover the beds with horse manure, about a carload to the acre. In early spring rake the manure in wide rows, cover the manure with salt hay, using 1 ton per acre. The 1st of May put on 800 pounds per acre of a good fertilizer.

As soon as it gets dry, start the pump. I run the rows at right angles to the main pipe, laying three-fourth-inch pipe 10 feet apart, parallel with the rows, have spigots about 60 feet apart on the small pipe, and connect with three-fourth-inch hose 50 feet long. A man changes the hose from row to row, running the water down the row. The longest period that I have been obliged to use the pump in any one year was nineteen days. My expenses for two men, fuel, and wear of the plant are about $3.50 per day.

Cost of irrigation.—The first cost of a plant similar to the one operated by Mr. Repp would be considerably less now than in 1884, the year when he started. Windmills have been improved since that time, and now less expensive gasoline engines are also entirely practicable for this work. Mr. Repp estimates the original cost of his entire plant at $600, the chief items of which are—

Worthington steam pump	$190
Steam boiler	150
400 feet rubber hose	40

The main iron pipe, connections, shed, stopcocks, etc., make up the balance of the initial cost.

Celery after strawberries.—As soon as the first crop of strawberries is gathered the vines are plowed under; that is, one summer is spent in preparing for the crop which is gathered the following spring. The patch is plowed in season to allow for the growing of another crop of some kind during the summer and fall. During the first years of the enterprise this second crop was celery. Celery was grown very successfully by irrigation, but it was difficult to keep for the winter market.

When setting out the celery plants in a dry time, shallow furrows were wetted before planting. After setting out, irrigation is accomplished by turning a furrow away from each side of the row and running water down these furrows. When the water has soaked in the furrow is turned back.

Lettuce after strawberries.—Mr. Repp's first attempt to irrigate lettuce was made in the extremely dry summer of 1895. The experiment was not a financial success on account of many hindrances at the start. The seed was sown about August 1 in drills. The seed proved to be poor and the field was replanted about August 15. Irrigation was effected by sprinkling with hose, very much in the same way that lawns are watered. The whole field of 1¾ acres was thoroughly wetted by four men in half a day. This watering was repeated twice a week until the lettuce was well started. There was no rain for three or four weeks after the seed was sown, but the waterings were sufficient to produce a good crop, though reduced in value by cold weather before it was ready for market.

It will be readily seen that the amount of water used on the lettuce was very small as compared with that used in watering strawberries. Full-grown strawberry vines will give off a great deal of water through the leaves on a hot day. The water that is transpired would be especially large from a field of strawberries grown as Mr. Repp grows them, where nearly half the field is thickly covered with thrifty vines.

During the ripening and picking season of strawberries, it will be remembered that on the field in question 200 tons of water are spread over an acre in a week (when no rain falls).

The amount of water used per acre on lettuce can be calculated approximately from the capacity of the steam pump. This will pump about 40 gallons of water a minute when the water is raised 7 feet, as in this instance. One-half day equals three hundred minutes. $300 \times 40 = 12{,}000$ gallons. This quantity was used on 1¾ acres twice a week. Twenty-four thousand gallons on 1¾ acres is 55 tons of water per acre once a week.

Irrigation of onions.—Mr. Repp has also irrigated onions, though his experience with this crop was less successful than with the others. He was unable to prevent blistering. Doubtless further study and experience will enable him to handle the water for this crop in a satisfactory manner.

Profits from irrigation.—Mr. Repp, having irrigated since 1884, is competent to give a very correct opinion concerning the average profits of irrigation with some crops.

For some years the 5½ acres under irrigation were devoted to growing strawberries and celery. One-half was irrigated and cropped each year. During the alternate years the land was devoted solely to the first year's growth of strawberry plants without irrigation. Immediately after the berry crop is removed the vines are plowed under, and about the middle of August the celery plants are put out.

Mr. Repp has irrigated strawberries, on the average, two seasons out of three since 1884. His smallest gross sales for any season in which irrigation was practiced were $300 per acre; average yearly gross sales of strawberries for twelve years from the 5½ acres were $250 per acre.

It should be borne in mind that only half the area (2½ acres one year, 3 acres the next) bore a crop each year. The average gross sales for bearing years were $500 per acre.

In addition to the profits from strawberries, were the profits from the celery, lettuce, etc., grown on the same land.

IRRIGATION ON THE FARM OF T. H. WHITNEY, GLASSBORO, GLOUCESTER COUNTY.

Pumping water for irrigation by water power.—In 1894 Mr. Whitney erected a plant to irrigate by water power several acres of land on one of his many farms about Glassboro.

Although the plant has not yet been used, because of a change in ownership, the arrangements are practical and provide for irrigation at a small expense, both initial and for operating. The construction and cost of the plant are the chief points considered. The accompanying sketch shows the locations, respectively, of the reservoir, dam, water wheel, pipes, etc.

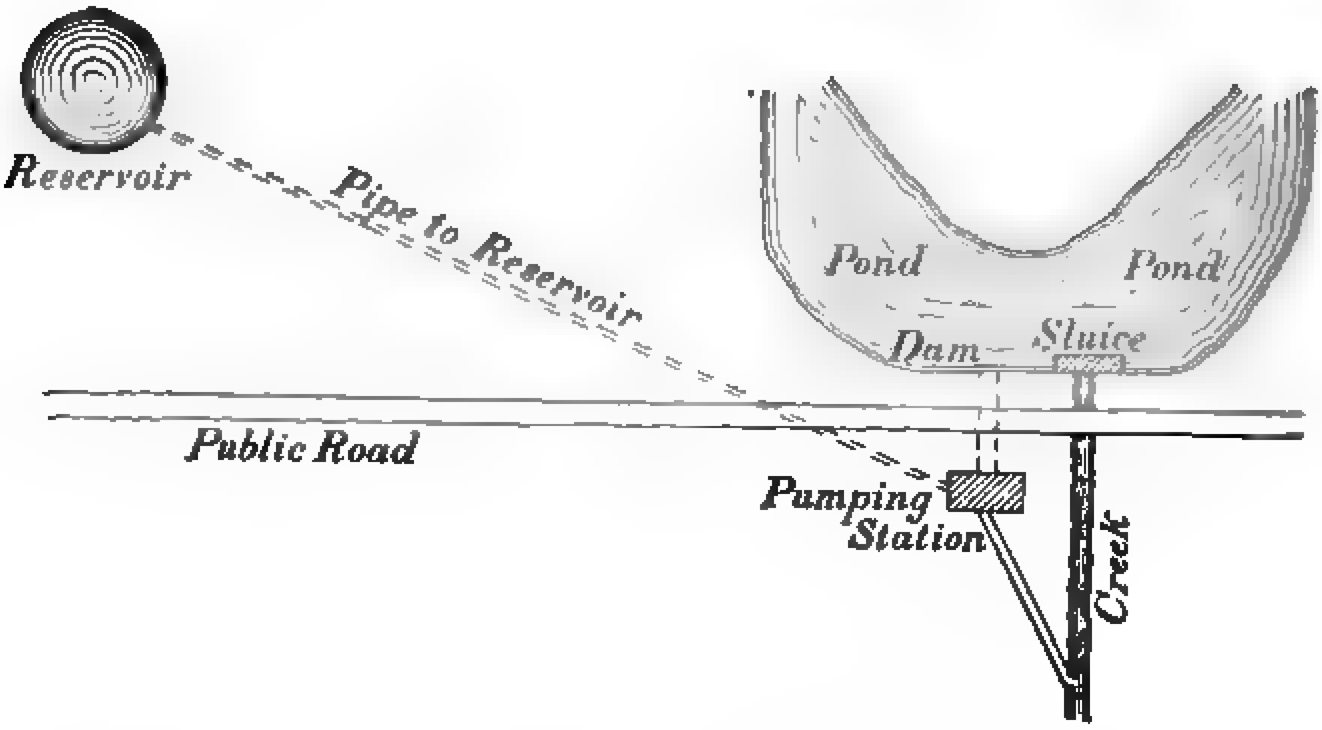


FIG. 4.—Irrigation plant on the farm of T. H. Whitney, Glassboro, N. J.

The pond on Mr. Whitney's farm covers about 3½ acres, and is supplied by two creeks, or rather several springs, since the pond extends nearly to the source of both creeks. These springs furnish a very steady supply of water. A large volume of water was flowing over the dam in December, 1895, while springs and creeks were drying up all over southern New Jersey on account of the prevailing drought. The dam is about 10 rods long. The water falls 9 feet at the sluice, and this fall is secured by backing the water only 300 or 400 yards up the stream.

The water passes through a large conduit from the pond under the road to the top of the 8-foot overshot water wheel. This water wheel is connected by cogged wheels to a Worthington double-action pump. The waste water then passes through a ditch to the main creek channel. The water for the reservoir is pumped through an underground clay

pipe, 2 inches in diameter. The reservoir is a bowl-shaped excavation, the bottom and sides being thickly cemented. The dimensions are, approximately, 9 feet in depth. Bottom circumference, 55 feet; top circumference, 125 feet; it has a capacity of over 50,000 gallons, and is located on a hill 40 feet above the level of the water in the pond.

The system is evidently less expensive than one in which steam power is used. The first cost need not be so great if the farmer uses his odd time to build the dam, lay the pipes, etc. And the running expenses consist mainly in the wages of the men who apply the water to the land, no engineer being required.

The number of farms where water power can be used in southern New Jersey is, however, small, since the average fall in creeks is but 8 or 10 feet per mile; in the northern sections of the State this method could be used in many places. The farmer owning 10 to 20 acres could not use water power in many cases. On large farms or in localities where several small owners could and would cooperate it would appear that water power could be used to advantage to pump for irrigation purposes.

Subirrigation.—Subirrigation is also practiced on Mr. Whitney's farms at Glassboro, and his method is quite unique, though there is probably very little land that can be irrigated in this way in the State.

A certain area of comparatively low land, underlaid with drain tile, became very dry during long droughts; to remedy this, a dam was built immediately below the point where the drain outlets into the creek, and the process of drainage was reversed. That is, the water of the creek was forced back into the drain tile, and out through the interstices into the soil, so that the latter was rendered moist within a few inches of the surface.

Mr. H. D. Chew, manager of Mr. Whitney's farms, has successfully irrigated onions and strawberries by this method.

IRRIGATION ON THE FARM OF JOSIAH H. SHUTE, PITMAN GROVE, GLOUCESTER COUNTY.

Garden irrigation.—Mr. Shute's outfit consists of an 8-foot iron turbine windmill set up on a 30-foot tower; two tanks of 500 and 2,000 gallons capacity, respectively; a Buckeye double-action force pump; piping from the pump to the tanks and irrigated field, and hose for distribution of water over the field. With a storage capacity of only 2,500 gallons, Mr. Shute successfully irrigated a little over 1 acre during the season of 1895, selling therefrom $250 worth of products, and having beside a plentiful supply of vegetables, etc., for family use.

The diagram (p. 56) will show the arrangement of his plant.

The dotted lines represent the underground pipes. The windmill and pump supply the house and barn with water, as well as the garden. The small tank is in the attic of the house, about 20 feet above the ground. All the water is pumped into this tank, which, when nearly full, discharges through the full length of pipe into the larger tank.

The 2,000-gallon tank is on the second floor of the barn. This almost constant flow of water through the pipes under the irrigated field has kept them clean.

Pipes furnished with faucets come up some distance above ground at four places along the main line, to which hose is attached long enough so that any part of the field may be watered.

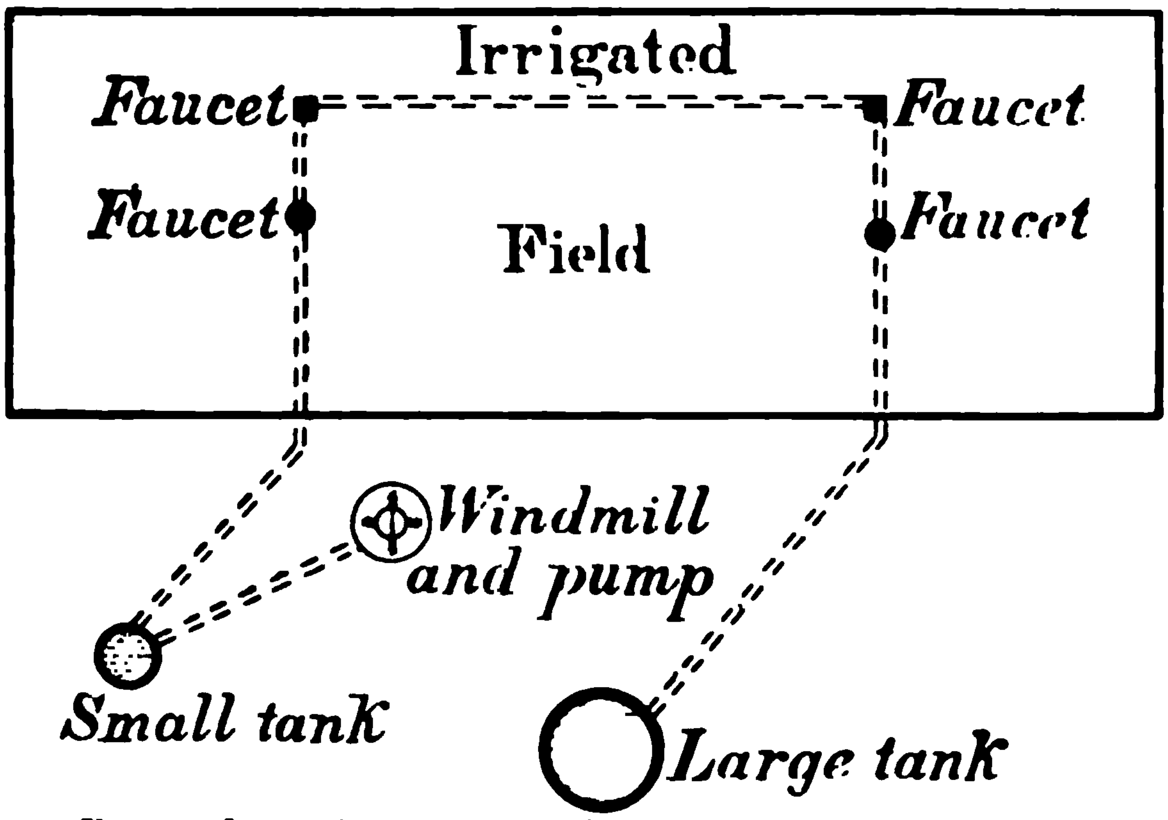


FIG. 5.—Irrigation system on the farm of J. H. Shute, Pitman Grove, N. J.

Crops irrigated.—Mr. Shute's specialty has been the growing of a crop of onions and celery on the same land in one season, and helping both crops by irrigation. He puts out his onion sets as early in the spring as possible, 1 foot by 3 inches. If there is dry weather while the onions are growing, he irrigates by sprinkling, or by flooding. Onions should be watered early in the morning, in the evening, or on a cloudy day. The onions are harvested early in July. Some are pulled early and sold in bunches with the tops on. While the onions are growing, the celery plants, White Plume variety, have been helped by watering, and about the middle of July are ready to transplant. These plants are set out 6 inches by 3 feet, the ground about them being thoroughly wetted. Other varieties would need to be 4 or 5 feet apart.

Mr. Shute irrigates his celery once in ten days, or two weeks. This operation is similar to Mr. Repp's method of irrigation of celery, already described. Mr. Shute has irrigated on a smaller scale, strawberries, lima beans, and other garden produce.

Cost of plant.—The chief items of expense in preparing for irrigation are as follows:

Iron turbine windmill and tower, not set up	$75.00
Double-action force pump	8.00
500-gallon tank	18.00
2,000-gallon tank	35.00
450 feet three-quarter-inch pipe, 4½ cents per foot	20.25
Total	156.25

The drive well from which the water is secured is not included in the cost of the plant, as it was put down primarily to supply the house and barn.

IRRIGATION ON THE FARM OF A. P. ARNOLD, VINELAND, CUMBERLAND COUNTY.

Mr. Arnold's windmill and reservoir located on the top of a hill were put up for other purposes than irrigation, the latter being incidental only.

The advantages for irrigation accruing from the location of the reservoir are apparent. After the water is in the reservoir, the whole farm can be irrigated without further use of power; and in case sufficient water can be secured from the well water rights might be sold to neighbors.

The soil on this farm is very sandy, with sandy subsoil, and, while perhaps requiring more frequent watering, is liable to suffer more from drought than a soil of greater water-holding capacity, hence benefits from irrigation are likely to be quite as great.

The reservoir is both strong and handsome. It would probably not be necessary to expend so much money on a reservoir for irrigation purposes only. However, there is very little chance of the walls of this reservoir cracking on account of the outward pressure of the water and letting the water soak out into the sandy soil.

The well was never lacking in water, although the summer and fall of 1895 were the driest known in Vineland for many years. The drive well is 70 feet deep, and it is about 35 feet to the water level. The water for irrigation purposes can be drawn from the reservoir through a pipe connected with the lowest part of the bottom and opening some distance down the hill.

Construction of reservoir.—The reservoir is approximately 45 by 90 feet in area; it is very shallow at one end, and gradually deepens until it is 7 feet deep at the other end, where the outlet pipe is connected.

The sides are built of stone and rise about 2 feet above the surface of the ground. The bottom and sides are thoroughly cemented.

Cost of the reservoir, windmill, and waterworks.—The cost as reckoned below does not include the wages for the labor that any farmer or his help can do at odd times.

Total cost of windmill set up, and waterworks for house and barn..	$120
Cost of reservoir..	130

There will be some further work and expense before everything is finished. A reservoir for irrigation purposes only should cost much less money. Probably $50 would buy all the material needed for a reservoir of much greater capacity, and a 12-foot windmill set up merely for the purpose of pumping water into the reservoir would cost much less than $120. There would be an expense not mentioned in the above estimate, viz, the cost of piping to the fields to be irrigated; and a larger windmill would be required if several acres were to be irrigated.

If large, tight reservoirs are provided, wind power may be made available for irrigation on a fairly large scale in southern New Jersey.

During summer droughts there is apt to be very little wind, so that

at the critical time, when large quantities of water are needed, there is very little available where wind power is the sole dependence, unless it has been pumped into reservoirs which are high enough above the land to be irrigated to permit the water to be distributed by gravity upon the land where it is needed.

IRRIGATION ON THE FARM OF THOMAS R. HUNT, LAMBERTVILLE, HUNTERDON COUNTY.

Mr. Hunt's place is located about 1 mile from the Delaware River, southeast from the town; the land is what is known in that section as "mountain soil;" it is a medium clay loam, and with a rather compact clayey subsoil. It retains moisture only reasonably well in dry weather; it is fairly well adapted for asparagus, celery, onions, and for the small fruits, raspberries and strawberries.

Mr. Hunt has used irrigation successfully for a number of years. Previous to 1892 he obtained his water from the waterworks supplying the town of Lambertville. In 1892 he put in his own plant, which consists of a Regan vapor engine, and the necessary mains. The engine is placed immediately upon the bank of a pond, which was built many years ago for the purpose of supplying water for general use. From the engine house he carries his main, a 2-inch pipe, directly west about 350 feet, where it reaches an elevation about 20 feet above the level of the pond, and is high enough to permit of his carrying water by gravity to any part of the farm which he desires to irrigate; about 100 feet from the engine house he carries a branch main of the same size about 200 feet south, in which T's are placed every 50 feet for hose connections; a 1-inch pipe is carried about 150 feet north to his garden, where a large portion of his plants are grown. From the westerly point he carries a 2-inch iron pipe main, arranged for connection in the same manner, about 200 feet north across the public highway. From this point the water is carried by means of fire hose for several hundred feet east and west connected with T's every 50 feet. The area capable of being watered under present circumstances is about 10 acres. The crops which have been irrigated up to the present time are strawberries, early cabbage, and celery, though the crops which he grows, and which may be irrigated by his system, consist of 2½ acres of strawberries, 3 acres of raspberries, 1½ acres of onions, 2 acres of celery, 2 acres of asparagus, and three-fourths to an acre of early cabbage. The variety of crops grown permits him to distribute his water over a larger area than if the entire area was in one or two crops.

The accompanying diagram (p. 59) gives a very good idea of the situation of the plant, and is described somewhat in detail, since it is representative of a large number of locations in the northern section of the State.

A represents the pond, which covers about half an acre, and is supplied by a stream large enough to meet all demands for irrigation. B is the engine house; C, C, C, C shows the location and direction of the mains, and D the 1-inch pipe running to the garden; E is the westerly

point of the main at which a T is placed; it has an elevation of about 20 feet above the level of the pond; at F is attached the fire hose, which may be carried several hundred feet, both west and east of the main. The areas showing asparagus and onions, south of the main pipe, slope toward the pond; the asparagus may be irrigated by attaching the fire hose at E. The area showing asparagus, peas, onions, and strawberries slopes so that it may be irrigated in two directions. The area to the north is quite irregular but is capable of irrigation mainly in the one direction, north; the garden is nearly on a level with the pond.

The cost of irrigation.—The main items of cost are gas engine, $260; iron pipe for main, $100; the cost of the main is somewhat low, because it consists of old boiler pipe, which was secured very cheaply. The cost of the old fire hose is merely nominal, and in the experience of Mr. Hunt is an excellent substitute for iron, where no pressure is exerted. For distributing he uses hose made from 12-ounce ducking, costing 12 cents per yard; this is cut into strips, three to the yard, and sewed together and then dipped into hot coal tar; he finds it very cheap and serviceable.

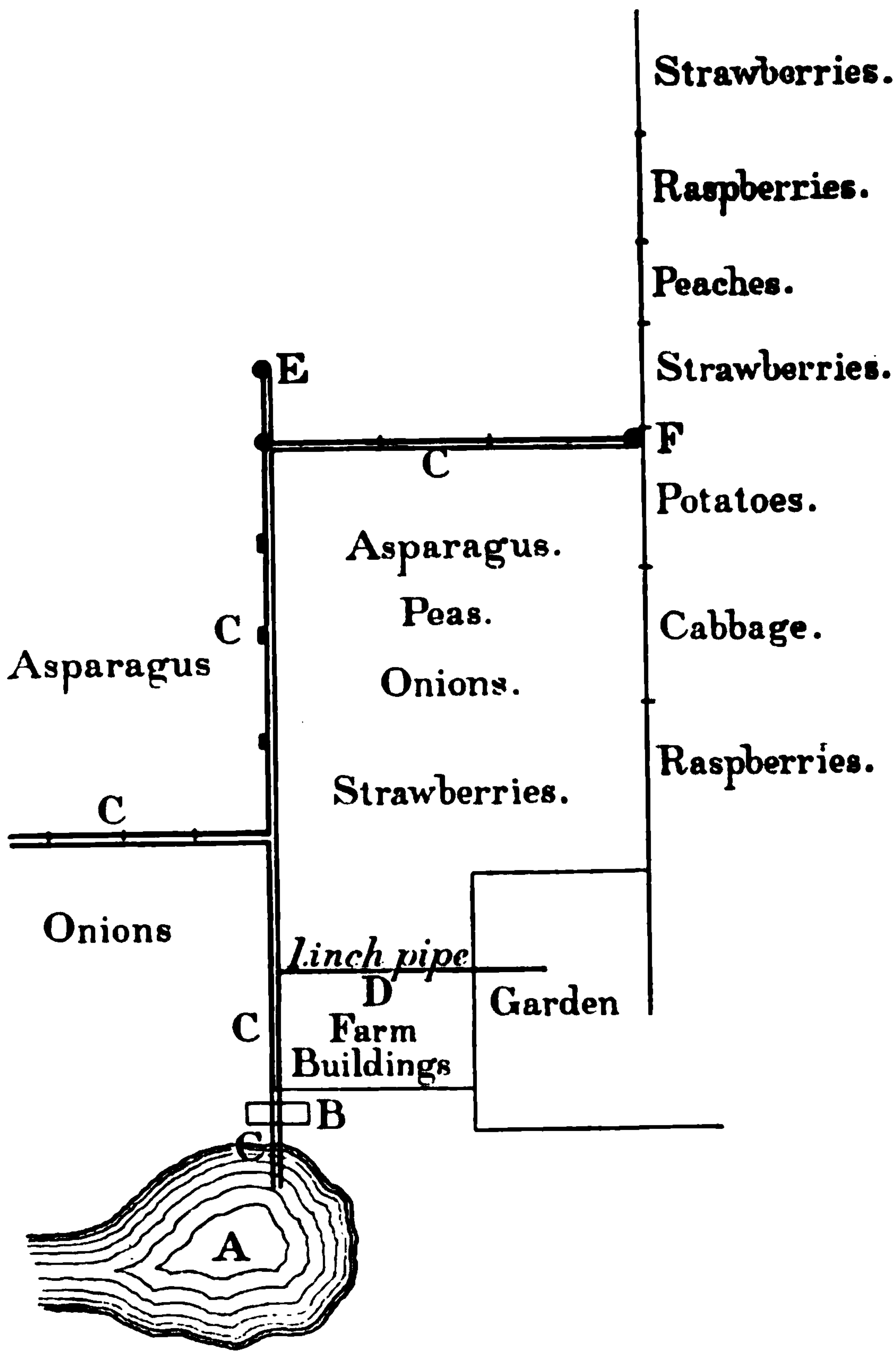


FIG. 6.—Irrigation system on the farm of T. R. Hunt, Lambertville, N. J.

The expense of running the engine ranges from 3 to 5 cents per hour, depending upon whether gasoline is purchased at retail or at wholesale, as the engine requires no attention after starting. The application of the water requires the attention of one man in order to prevent waste. It is applied entirely in rows, except upon growing plants, as cabbage and celery, when it is sprinkled.

The distribution is effected by means of a trough or gutter, the sides of which are perforated at different distances, permitting an adjustment to the width of the rows of the various crops grown. In irrigat-

ing strawberries, however, the water is simply allowed to run between the rows under the mulch. The capacity of the engine is 1,500 gallons per hour, which will irrigate thoroughly at least half an acre per day. Irrigation is never practiced until the ground becomes dry, and in the case of cultivated plants, as celery, cabbage, etc., the land is cultivated as soon after as it is dry enough, to prevent baking.

Mr. Hunt regrets now that he did not put in an engine with a capacity of 4,000 gallons an hour, a quantity that could be carried by his main, and which, at the present time, would cost but little more than the one he now has.

The advantages derived.—The first year in which the plant was in operation—1892—the irrigation of 1 acre of celery more than paid for the entire cost of the plant, and Mr. Hunt estimates that the value of the water merely for the purpose of wetting his plants, both before and at the time of setting, pays annually more than the initial cost of the plant, and though he has kept no accurate record of the profits secured from irrigation, the good results are so apparent that anyone visiting his place is deeply impressed with the value of the system. His berries, particularly, are of very fine quality; in fact, so superior that he is able to fix his own prices in his chief markets, Lambertville and Scranton.

POSSIBILITY OF PUMPING LARGE QUANTITIES OF WATER FROM WELLS FOR IRRIGATING PURPOSES.

In the two cases cited where water was pumped from wells to be used for irrigation, only a small acreage was irrigated. In order to discover if it were possible to pump large quantities of water from wells, the waterworks of Vineland, Cumberland County, N. J., were investigated.

The water for the Vineland waterworks is pumped by steam power from fourteen driven wells, 2½ inches in diameter, to a high reservoir; the distance from surface of water in the wells to the top of the tank used as a reservoir is 95 feet. The average amount of water pumped daily is 250,000 gallons. It was impossible to secure even approximate data concerning the cost of pumping this water.

The experience of the Vineland Waterworks Company proves that it is possible to pump enough water at one place, at least in southern New Jersey, to irrigate a large tract of land. Two hundred and fifty thousand gallons of water per week to an acre will irrigate most crops effectually, even during a prolonged drought. With 250,000 gallons a day from 5.5 to 6.5 acres could be irrigated without the use of large reservoirs. If large reservoirs were used, the irrigated acreage could be greatly increased.

It is not probable that such prolific wells as were found by the Vineland Waterworks Company exist in many places. But, on the other hand, not many farmers would want to irrigate more than 5 acres. It is quite probable that the most economical method of irrigation will

prove to be for several farmers to cooperate in building a central pumping station, the water to be conveyed from this station to large reservoirs on the farms of the cooperating members.

IRRIGATION EXPERIMENTS IN NEW JERSEY.

In 1895 arrangements were made that rendered it possible to secure on a farm of the New Jersey Experiment Station an abundance of water for irrigation purposes, and plans were made at once to study the question of irrigation in a broad way, both in reference to the kind and variety of crops and the methods of applying water. The cost of irrigation is not included in the study further than to record the expenses

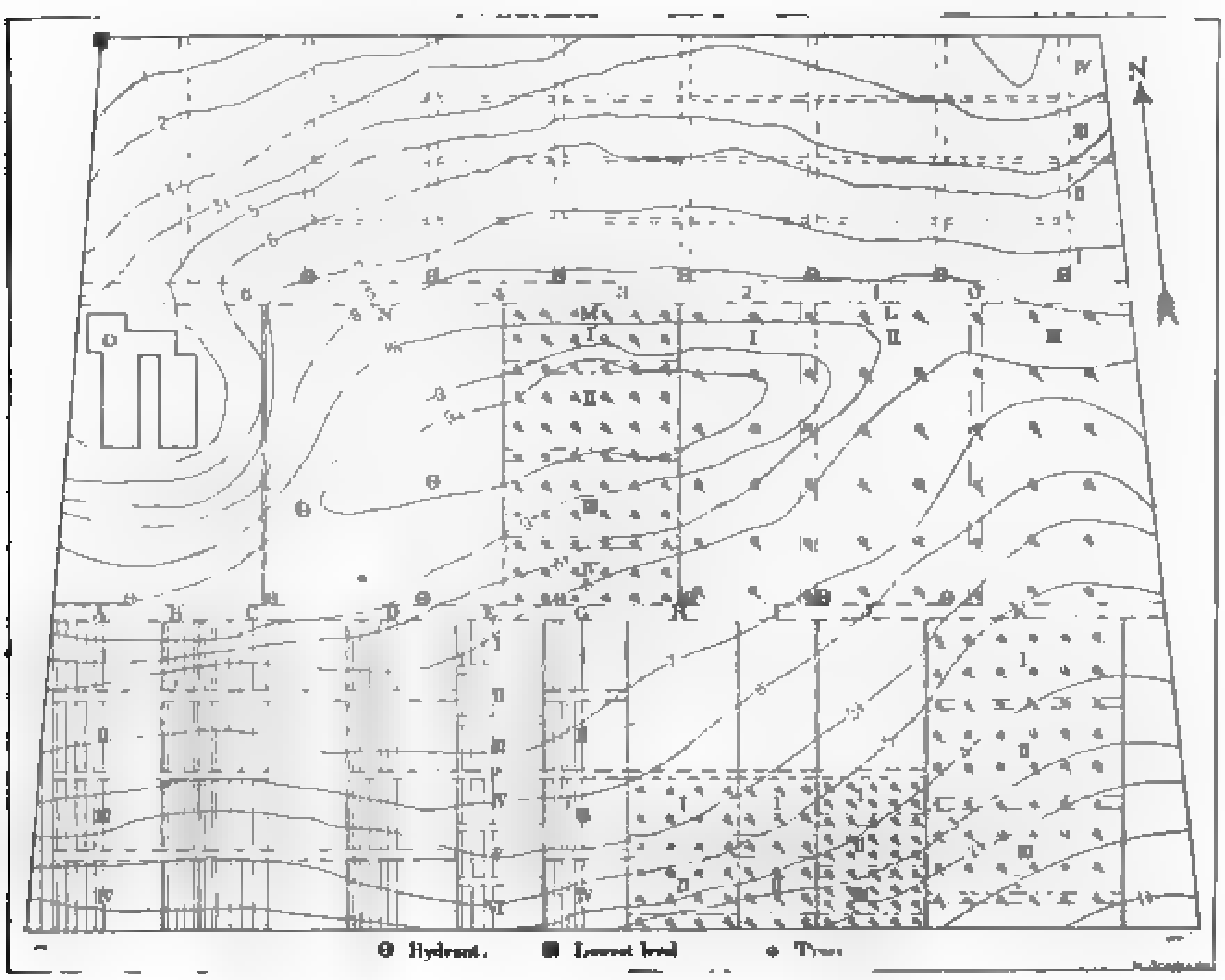


FIG. 7—Map of area devoted to irrigation experiments at the New Jersey Experiment Station.

attending the application of the water, as the conditions under which the water was obtained could not be duplicated throughout the State.

The crops that are growing now, and which are to be grown later, include a large number of vegetables, which, as a rule, require an abundance of water in order to secure earliness and high quality, and which are especially adapted to the conditions existing in the State; chief among these are asparagus, celery, cucumbers, cabbages, beets, beans, peas, peppers, potatoes, tomatoes, and turnips, including both early and late crops where the kind of vegetable permits. Among the fruits are included strawberries, blackberries, raspberries, gooseberries, currants, plums, cherries, and pears.

The methods to be investigated include both surface and subirriga-

tion. The furrow and flooding system for surface irrigation will be given careful trial, while in subirrigation both the usefulness of the various kinds of tile and the influence of depth of placing them will be studied. The plants selected include, as a rule, the standard sorts and varieties, and wherever practicable each irrigated area will include from two to four plats, each treated in a different manner, particularly in respect to manuring. The accompanying map, with description of the plant, indicates the plan and scope of the work outlined.

The experiment ground contains 7 acres, separated by lanes 9 feet wide into three divisions, the higher ground in the middle division. The contour lines show a fall of 9¼ feet from the highest to the lowest points, and that upon a large portion of the area there is a reasonable uniformity in the slope of the land, thus permitting a ready and sufficiently rapid flow of water. The water is supplied by a 3-inch main, which runs through the middle division; T's are placed every 75 feet, from which laterals, 1 inch inside diameter, are carried both north and south, ending in hydrants raised 3 feet from the ground and provided with faucets to which hose may be attached for distributing the water. The fall from the reservoir is about 9 feet, thus affording a reasonably rapid flow from the laterals, and the supply is ample for the maximum demands for irrigation purposes. The division lying on the north contains about 2 acres, and is separated into four plats, numbered in the map I, II, III, IV, which are divided again north and south into seven series of plats, indicated by the numerals 0, 1, 2, 3, 4, 5, and 6; a portion of each series, approximately one-sixth, is arranged for irrigation; the water runs north from the standpipes, and may be applied first to Plat IV, then to III, etc., or to I, II, and III, etc., as the line of experimentation may dictate.

With the exception of asparagus, the different kinds of vegetables mentioned as under experiment are grown on these plats, and various methods of surface and subirrigation used are practiced.

The area lying on the south side contains 3½ acres, and is divided into ten plats, running north and south, marked A, B, C, etc., the area of each plat being determined by the kind of crop and object of the experiment; the plats are also subdivided into belts, numbered I, II, III, etc., running east and west. With the exception of Plats B and K, one half of each plat is arranged for irrigation.

For example, Plat A contains six varieties of asparagus, represented by the lines running north and south; these varieties are duplicated on the blank space which represents the irrigated area of the plat. Plat C contains six varieties of blackberries; Plat D, six of raspberries; Plat E, four of currants; Plat F, four of gooseberries; and Plat G, six of strawberries. These plats are also subdivided into belts I, II, III, etc., for the purpose of studying methods of culture and manuring. In Plats H, containing plums, I, cherries, and J, pears, the upper portion is irrigated, and each belt of two rows of trees each in the plats is

separated from the other by a single row of trees containing different varieties of the same kind of fruit for a variety test; the purpose of this separation being to prevent cross feeding.

Plats K, in which standard pears are set, L, containing apples, and M, peaches, are situated in the middle division on the higher portion of the land, and are not duplicated for irrigation, though it may be practiced in case necessity demands. Plat N is arranged more particularly to study methods of irrigation; it contains a number of kinds and varieties of berries and vegetables in which it is planned to study the advantages and disadvantages of a number of methods of applying the water, both by surface and subirrigation methods. O shows the plant houses, where subirrigation is a feature of the work planned for the winter season.

It will be observed from this description of the plant that opportunity is afforded for a broad study of the question of irrigation as applied to the crops of the greatest importance in our State. A small part only of this plant was in operation in 1895; it was finished too late to permit of a proper study of the effect of irrigation, except in case of a few late vegetables. Irrigation began on September 17 and continued until the end of the season upon beans, peppers, eggplants, tomatoes, turnips, and celery. For eggplants and tomatoes irrigation began too late to be of service; the turnip crop was ruined by club root, thus leaving but three crops from which positive data could be secured. The complete data obtained have already been published[1] and may be summarized as follows:

[For beans, stated] in terms of good-sized pods, the average yield of the nine nonirrigated belts was 17 pounds and 1 ounce, while the yield from the irrigated belt was 45 pounds, or nearly three times as many, besides being much larger sized and of finer color and quality.

For peppers the average yield upon the eleven nonirrigated belts was 717 fruits, while the number upon the irrigated belt reached 1,277. This does not show the whole difference, for by measure an unirrigated belt gave 6½ peach basketfuls, with a total weight of 80 pounds, and the irrigated belt 11¼ baskets, weighing 147 pounds. The difference is still more than these figures show, for the irrigated ground gave much better looking peppers in plumpness and color than the nonirrigated land, with the quality far superior. The fruit from the irrigated plants would sell at the highest price, when those from nonirrigated plants might go at a low figure.

The increase of 4¾ baskets of peppers, to say nothing concerning the great superiority of the whole crop over that of the nonirrigated belts, cost for the water 24½ cents (24.46), which in round numbers is 5 cents (5.14) per basket.

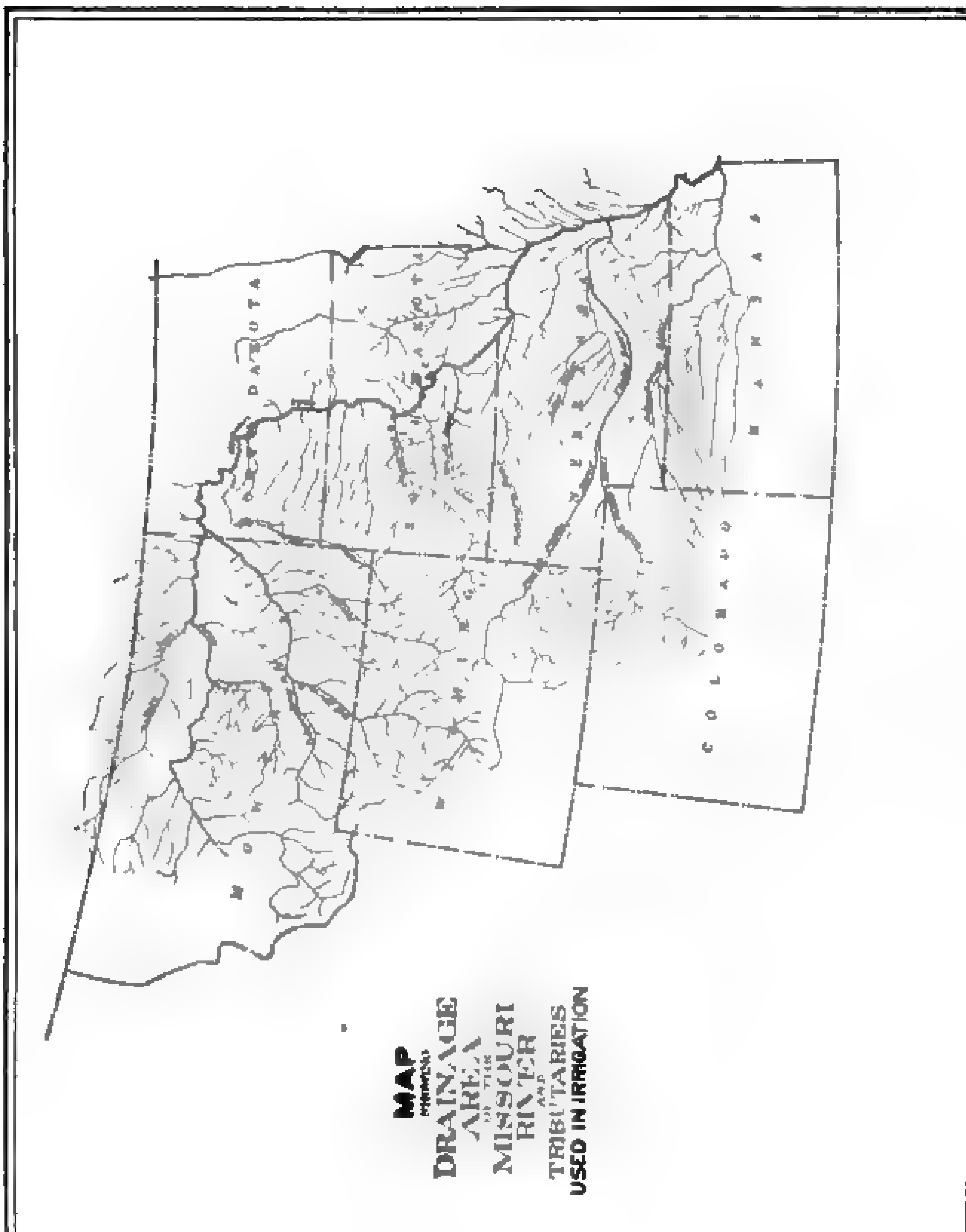
The total weight of celery was 465½ pounds, 329½ pounds being produced in the irrigated and 136 pounds in the nonirrigated rows. In round numbers this is two and one-half (2.40 to be exact) times as much celery upon the irrigated as upon the nonirrigated land. However, these figures do not indicate the full difference of market value, for the irrigated celery was of good size and quality, readily salable at a fair price, while the nonirrigated rows yielded a crop that was worth less than the cost of production. After the plants were prepared for market by removing worthless outside leaves and the roots, it was shown that the loss from the irrigated

[1] New Jersey Stas. Bul. 115.

was 28.57 per cent, while from the nonirrigated it was 40 per cent, which is a much greater loss for the smaller plants than for the larger.

The difference between the marketable products of the two rows is in round numbers three to one; but when the selling price is considered the difference is not far from eight to one in favor of irrigation.

Irrigation is undoubtedly practicable in New Jersey. It only remains to demonstrate by further study and experiment its adaptability to the varying conditions, in reference to crop and soil, the methods by which it may be most economically accomplished, and the advantages that may accrue therefrom, in order that a valuable resource of the State, namely, water supply, may be largely utilized in this direction.



MAP OF MISSOURI RIVER BASIN.

U. S. DEPARTMENT OF AGRICULTURE,

OFFICE OF EXPERIMENT STATIONS.

WATER RIGHTS

ON THE

MISSOURI RIVER AND ITS TRIBUTARIES,

BY

ELWOOD MEAD,
STATE ENGINEER OF WYOMING.

WITH PAPERS ON THE WATER LAWS OF COLORADO BY JOHN E. FIELD, STATE ENGINEER, AND OF NEBRASKA BY J. M. WILSON, STATE ENGINEER.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1899.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., December 15, 1898.

SIR: I have the honor to transmit herewith an article containing a discussion of the irrigation laws which control the diversion and use of water from the Missouri River and its tributaries, prepared by Prof. Elwood Mead, State engineer of Wyoming, in accordance with instructions given by the Director of this Office.

This is the first of a series of bulletins to be prepared in accordance with the provisions of the clause in the appropriation act for this Department for the current fiscal year authorizing the collection "from agricultural colleges, agricultural experiment stations, and other sources, including the employment of practical agents, of valuable information and data on the subject of irrigation, and publishing the same in bulletin form." The general supervision of this work has been assigned to the Director of this Office.

It was decided that the best way in which the Office could get the advice which it needed for the formulation of plans of work along the most useful lines was to call a conference in the irrigated region of experiment-station officers and irrigation engineers who had been most largely engaged in recent years in making experimental inquiries in irrigation, or in dealing with the administrative and practical problems involved in the use of water for irrigation in the West. This conference was held at Denver, July 12 and 13, 1898, and was attended by experiment-station officers from California, Nebraska, Colorado, Utah, Montana, and Wyoming, and the State engineers of Wyoming, Colorado, and Nebraska.

After careful consideration it has been determined to confine the work on irrigation for the present to two general lines: (1) The collation and publication of information regarding the laws and institutions of the irrigated region in their relation to agriculture, and (2) the publication of available information regarding the use of irrigation waters in agriculture as shown by actual experience of farmers and by experimental investigations, and the encouragement of further investigations in this line by the experiment stations.

As the extent and importance of the use of water for irrigation have increased in that vast region of the United States in which the rainfall is not sufficient for successful agriculture, many perplexing questions have arisen regarding the legislation and methods of administration required to secure the most equitabl[illegible] vailable water and to promote the most advant[illegible] ial and social life in the communiti[illegible] an adequate supply of water fo[illegible]

It is believed that this Department may greatly aid in the right solution of these fundamental problems by setting forth the facts and impartially discussing the principles involved in the just adjudication of water rights. As the matter vitally affects a considerable number of States and Territories and many of the problems overrun the State lines, it seems entirely appropriate that the National Government should undertake to collate and diffuse the needed information. In the treatment of the subject of water rights, the comparative method seemed most likely to bring out the merits as well as the defects in existing laws and methods of administration in the several States, and this method has therefore been pursued in the preparation of this bulletin. On the other hand, the vast extent of the irrigated region and the peculiar problems presented by different large areas made it unadvisable to attempt to cover the whole field in a single bulletin. It was deemed preferable for this first bulletin to select a single region covering portions of several States in which there was in general sufficient likeness in the agricultural conditions as affected by irrigation to render it possible to make a clear and definite statement of the problems of water rights and of the directions in which improved legislation is required.

The author of the major portion of the bulletin is thoroughly familiar with the region of which he writes, and has had a long and successful experience as irrigation engineer and administrator of irrigation laws, as well as a student of the agricultural problems of this region. Besides the State of Wyoming, there are two States in the Missouri Basin in which the streams are under State control and in which State officials protect the rights of appropriators of water for irrigation purposes. These officials are better prepared than anyone else to discuss the efficiency of the irrigation laws which they attempt to enforce, and it is considered very fortunate that the cooperation of Hon. John E. Field, State engineer of Colorado, and Hon. John M. Wilson, State engineer of Nebraska, could be secured to prepare the discussion of the laws of their respective States. The success which these officers have achieved in the discharge of their complicated and important duties gives to their views a special interest and value. In addition to their contributions, valuable assistance has been rendered by the Hon. J. S. Dennis and Wm. Pearce, of Canada; Hon. E. D. Wheeler, irrigation commissioner of Kansas; Hon. Allen Cox, attorney, of Wakeeney, Kans.; Hon. S. A. Cochrane, State engineeer of South Dakota; Hon. Edward Van Cise, attorney, of Deadwood, S. Dak.; F. L. Sizer and other members of the Montana Society of Civil Engineers; and many others.

This bulletin is respectfully submitted, with the recommendation that it be published as Bulletin No. 58 of this Office.

Respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

CONTENTS.

ILLUSTRATIONS.

WATER RIGHTS ON THE MISSOURI RIVER AND ITS TRIBUTARIES.

INTRODUCTION.

For every acre of irrigated land there has to be a right to water. The title to the water is of as much importance as the deed to the land. It is much harder to establish. These rights take more forms than the rivers they control, and are acquired by as many methods as there are States to frame laws. In one respect they are alike: No matter whether the user of water derives his title direct from the State, buys it from a ditch company which furnishes water for hire, or from the holder of a speculative claim, it is a source of more perplexity at the outset, and of more hours of anxious thought afterwards, than all the other problems of irrigation combined. This is due in part to the fact that the ownership of streams is new and the nature of property rights therein uncertain; but, whatever the reason, the fact remains that the irrigator whose water right does not furnish grounds for either an inquiry or a grievance is a rare exception. Nor are irrigators alone in finding the limits of a water right hard to define or the problems of stream ownership hard to solve. Lawmakers and courts have both found them equally perplexing.

The reasons for this are not obscure. Because of uncertainty of what these rights should be, or difference of opinion on that question, the irrigation laws of many States have been made so ambiguous and contradictory that the finite intellect is not able to interpret their meaning. As a result there are laws and court decisions to sustain about every view of stream ownership of which the mind of man can conceive, and in some cases they are all found in the statutes and decisions of a single State.

The following will serve to illustrate what is meant:

The General Government in 1866 practically abrogated all control over nonnavigable streams used in irrigation by recognizing local laws and customs on this question. Subsequently it passed the desert-land act, which defines what a right to the use of water in the irrigation of that land shall embrace.[1] This act has been made a basis for a conten-

[1] *Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,* That it shall be lawful for any citizen of the United States, or any person of requisite age "who may be entitled to become a citizen, and who has

tion on the part of many irrigators that they do not derive their rights from State laws at all but from this national act, and that the party who acquires a title to land under the desert act is independent of State laws governing water rights. The General Government, however, does not in any way exercise control over streams or protect these rights, but, on the contrary, recognizes local laws, in many instances accepting as evidence of title to water documents which have no more real force and effect than would a certified copy of the Declaration of Independence.

One of the States included in this discussion has made the common-law doctrine of riparian rights a part of its organic law. The supreme court of another State, in setting this doctrine aside, thus describes the effects of its adoption in any State where irrigation is required:

Riparian rights have never been recognized in this Territory, *or in any State or Territory where irrigation is necessary*, for the appropriation of water for the purpose of irrigation is entirely and unavoidably in conflict with the common-law doctrine of riparian proprietorship. If that had been recognized and applied in this Territory, it would still be a desert; for a man owning 10 acres of land on a stream of water capable of irrigating 1,000 acres of land or more near its mouth could prevent the settlement of all the land above him; for at common law the riparian proprietor is entitled to have the water flow in quantity and quality past his land as it was wont to do when he acquired title thereto, *and this right is utterly irreconcilable with the use of water for irrigation.* The legislature of this Territory has always ignored this claim of riparian proprietors, and the practice and usages of the inhabitants have never considered it applicable, and have never regarded it. (Stowell *v.* Johnson, 26 Pac. Rep., 290.)

The same State which has in one law required that streams shall not be diminished in volume has in another law legalized the construction of ditches to take water out of those streams and the appropriation of the water to fill those ditches.

In another State where the constitution makes water *public* property and dedicates its *use* to the people the holders of rights thereto are treating them as personal property and selling the stream's flow exactly as they would bushels of wheat or yards of cloth. The laws of this State require that appropriations shall be for beneficial uses, yet appropriations for large volumes of water are being sustained where it is

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filed his declaration to become such," and upon payment of twenty-five cents per acre, to file a declaration, under oath, with the register and receiver of the land district in which any desert land is situated, that he intends to reclaim a tract of desert land not exceeding one section, by conducting water upon the same, within the period of three years thereafter: *Provided, however,* That the right to the use of the water by the person so conducting the same on or to any tract of desert land of six hundred and forty acres shall depend upon bona fide prior appropriation; and such right shall not exceed the amount of water actually appropriated, *and necessarily used for the purpose of irrigation and reclamation;* and all surplus water over and above such actual appropriation and use, together with the water of all lakes, rivers, and other sources of water supply upon the public lands, and not navigable, shall be held and remain free for the appropriation and use of the public for irrigation, mining and manufacturing purposes, subject to existing rights. (Forty-fourth Congress, 2d session, chap. 107.)

admitted that the water was not used for any purpose, beneficial or otherwise, for twenty years after the priority of right was established.

In some States the law is so ambiguous that no one can tell from its terms whether a right to water is acquired by posting a notice on the bank of the stream, by building a ditch to divert it, or by spreading it over the arid plain to make it productive. There is equal uncertainty about the nature of the title after it is acquired. Some contend that whoever files a location claim on a stream becomes the absolute owner of what he claims; others that the right is restricted to the capacity of the ditch, but that the ownership is absolute and, when once acquired, can be moved to other ditches or other lands. There are others who hold that streams are public property; that no right except that of use is or should be conferred; that this right is inseparable from the place where acquired or the use by which acquired, and that rights for irrigation do not inhere in either the individual who makes the filing, or in the ditch which diverts the stream, but in the land reclaimed, and is inseparable therefrom. In the decisions of a single State it has been held that water can not be appropriated for one purpose and then used or sold for another; in a succeeding decision the right to sell an appropriation irrespective of use has been upheld. In the same State it has been held in one decision that the size of the ditch determines the volume of the appropriation, regardless of the use to which applied, while in another decision the volume of the appropriation was determined by the acres which had been irrigated, and in still another decision the construction of a ditch on one side of the stream was held to have established a right to water for land on the opposite side of the stream which had never been irrigated and for which the ditch was not built for many years after the right was acquired.

As yet the subject is new. Laws and customs are in their formative period. The views of each user of water are modified by his knowledge or ignorance of the experience of other lands, and by the influence on his personal welfare which the adoption of any particular policy would have. These conditions make it hard to enact laws which will commit a State to any one of these doctrines. Legislators have preferred to avoid the subject or to confine themselves to glittering generalities which begin and end nowhere so far as the creation of a working code of laws is concerned. This policy has been encouraged by the fact that the ultimate importance of agriculture by irrigation has been obscured by the present prominence of mining and by the greater profit to a few stockmen to be gained from the free use of the public land as an open range.

But the irrigated lands of the West are fertile; the climate is healthful. In the noble mountains of this region are some of the world's greatest sanitariums, where many have to go to live. The remaining public lands are arid, and irrigation is the hope of the home seeker.

With or without laws for their orderly and peaceful use, the rivers of the West have been diverted. Cities have been built where once the coyote was the only inhabitant. The sagebrush and cactus plain is now dotted with orchards and grain fields. The river which once ran idly to the sea has become the lifeblood of the industries and the hope of more than one-fourth of this country. On its right division and use hinge the returns from the millions invested in ditches and canals, and the value of thousands on thousands of homes.

Colorado leads all the States in the production of the precious metals, but the yearly return from her irrigated fields is nearly double the value of the yearly output of the mines. In a half century the cash value of rights to her streams has risen to over seventy millions of dollars.[1]

On many rivers there are now a multitude of claims to the common supply. These rights have to be defined in some way. If laws do not define them, a resort to the courts is all that intervenes between the just rights of water users and anarchy. In many States the exigencies created by a failure to enact an administrative code have compelled the courts to become practically both the creators and enforcers of water laws. They have to devise a procedure for adjudications, supplement the statute law in deciding what rights have been established, and finally have to protect irrigators' priorities by a liberal exercise of government by injunction. The growing volume of this litigation, together with the uncertain and contradictory character of many of the decisions, is making it a heavy burden to irrigators and a serious menace to progress. Unless it can in some way be restricted, it threatens to impair the value of investments in ditches and the success of this form of agriculture. In ten years the water-right litigation of one State is estimated to have cost over a million dollars. In many sections it has exceeded the money expended in constructing the ditches in which it has its origin.

These conditions are not met with in every State. In two States it costs an appropriator less to establish his right to water than it does to prove up on the land it fertilizes, and it is done by the same direct methods. Litigation is conspicuous for its absence, either in acquiring water rights or in preventing interference by subsequent appropriators with their enjoyment. In these two States public control of streams is as much a part of the State government as is the control of public land a part of the National Government.

Wherever rights to water are restricted to its beneficial use, and where such use is followed promptly by the determination of the extent of such rights, controversies are as rare as they are over land filings; and where these laws begin by prohibiting speculative filings and end with adequate protection for just ones there are no more contests among farmers who depend on rivers than there are between those

[1] Address of Hon. E. S. Nettleton, ex-State engineer.

who depend on rain. Litigation does not arise because irrigators desire it. It has its origin either in ignorance of the law or in its imperfections.

To end it the users of water must be informed. They not only need a better understanding of their own laws, but to know how rivers are managed in other countries, so that their experience may be utilized. In a large measure we are dealing blindly with a question which in all ages and all lands has taxed the wisdom of the ablest minds. The General Government aids settlers by publishing explicit directions for filing on public land and acquiring title thereto, but no such instructions have ever been issued to direct users of water in acquiring a right to the volume needed to give the irrigated home a value. The pages which follow are intended to supply in part this omission.

CHARACTER OF IRRIGATION FROM MISSOURI RIVER.

In considering the problems which these different State laws present none seem more perplexing, nor in their larger aspect more illogical, than the change which occurs in the control and in the forms of ownership of a river when it crosses a State boundary. The Big Horn River is the same stream after it leaves Wyoming that it was before it crossed the imaginary line which separates that State from Montana, and users' needs are the same; but the interval required in this passage marks a revolution both in the forms of proprietorship in the stream recognized by law and in the manner of their creation. It has seemed, therefore, that by confining the discussion to a single river the nature of the fundamental problems could be more clearly set forth. The States embraced in this discussion are Kansas, Nebraska, North and South Dakota, Wyoming, Montana, and Colorado. They form a part of the Missouri River basin and their laws control the portion of its waters used in irrigation. The following are the reasons for selecting this stream:

It is the largest river of the arid region. The area and fertility of land which can be reclaimed makes it certain that in time the value of its products and the number of people supported by agriculture will make it a worthy rival of the Nile. The most effective laws have been enacted by the States drained in part by its tributaries, so that we are dealing with the best rather than the worst conditions. Throughout the entire arid and semiarid district which it traverses agriculture is of the same character. It is one of the foremost stock-raising and grain-growing sections of the country. So far as its productions or the needs of its farmers are concerned, there is no more reason for half a dozen water laws than there would be for that many different systems of acquiring titles to land. On the other hand, the complications which would grow out of a half dozen land systems are not to be compared to the complications which are being created by half a dozen different water laws, because these different titles to water and different methods of acquiring them all refer to a common supply.

Irrigation in the Northwest Territories of Canada.—Some of the tributaries of the Missouri rise in the Northwest Territories of Canada—a region so like Montana and Dakota that laws which work well in one country will be a success in the other. The application of the Canadian laws to a portion of the Missouri's watershed makes their consideration desirable, aside from their influence on international water-right questions. We ought to know what those laws are. They are worthy of our study because the control of streams in those Territories is only approached in efficiency and directness by two of the States on this side of the boundary. The Northwest Territories have therefore been included.

NATURE OF THE PROBLEMS.

The map of the Missouri Valley (Pl. I, frontispiece) shows the region included in this discussion. It embraces an area of 491,400 square miles—almost twice as large as the original thirteen colonies. In over two-thirds of this area irrigation is a necessity; in all it would be a benefit. The stream gaugings at Kansas City give the run-off of this watershed, and in a rough way enable us to determine the extreme limits of the acreage which can be reclaimed. The diagram on page 13 shows both the daily and seasonal discharge for the years 1881 and 1885. From these it will be seen that the water which ran to waste in 1881 (67,937,000 acre feet) would have more than sufficed to cover all New England 1 foot deep. In 1885 this discharge fell to 48,377,000 acre-feet, and in the other years in which the record has been examined it fluctuated between these two extremes. Not all of this water can be utilized. The fluctuations in discharge are much greater than the variations in the use of water. Without storage a very large percentage must run to waste, and even with storage not all can be utilized.

There have not been enough measurements of the quantity of water required to irrigate an acre of land to afford a basis for even an approximate estimate of what the available volume of this stream will reclaim. An acre of any crop in Nebraska or Kansas, where there is 20 inches of rain, requires less water than it does in parts of Wyoming, where the rainfall is only one-half this depth. It will also depend on the kind of crops grown. It takes more water to produce an acre of native hay than it does 2 acres of potatoes, so that there are numerous elements which make any attempt at fixing the ultimate acreage which will be irrigated a hazardous performance. Taking the results which have been secured with smaller volumes of water, where both the acreage of land and the water which reclaims it have been definitely determined, it does not seem an extravagant estimate to say that the Missouri and its tributaries are capable, if rightly used, of reclaiming from barrenness nearly a half million 80-acre farms; nor does this contemplate exhausting the stream. A large percentage of the volume diverted will return, so that if every drop which enters the river and its tributaries were taken out so much would return that the most apparent

result would be the equalizing of the flow of the main stream. There would be less water in June and more in October. It must be remembered that the diagram (fig. 1) shows only the surplus. On many of the tributaries the summer flow was entirely used at the time these measurements were made. At that time millions of dollars had been expended in ditches, and many thousands of homes were being made prosperous by the use of the water. Since that time many more millions have been expended, but still the floods of June are a source of destruction to the dwellers along the river below, while the escape of the early summer's discharge of water is a still more serious injury to the farms above. We are seriously considering the beginning of a great

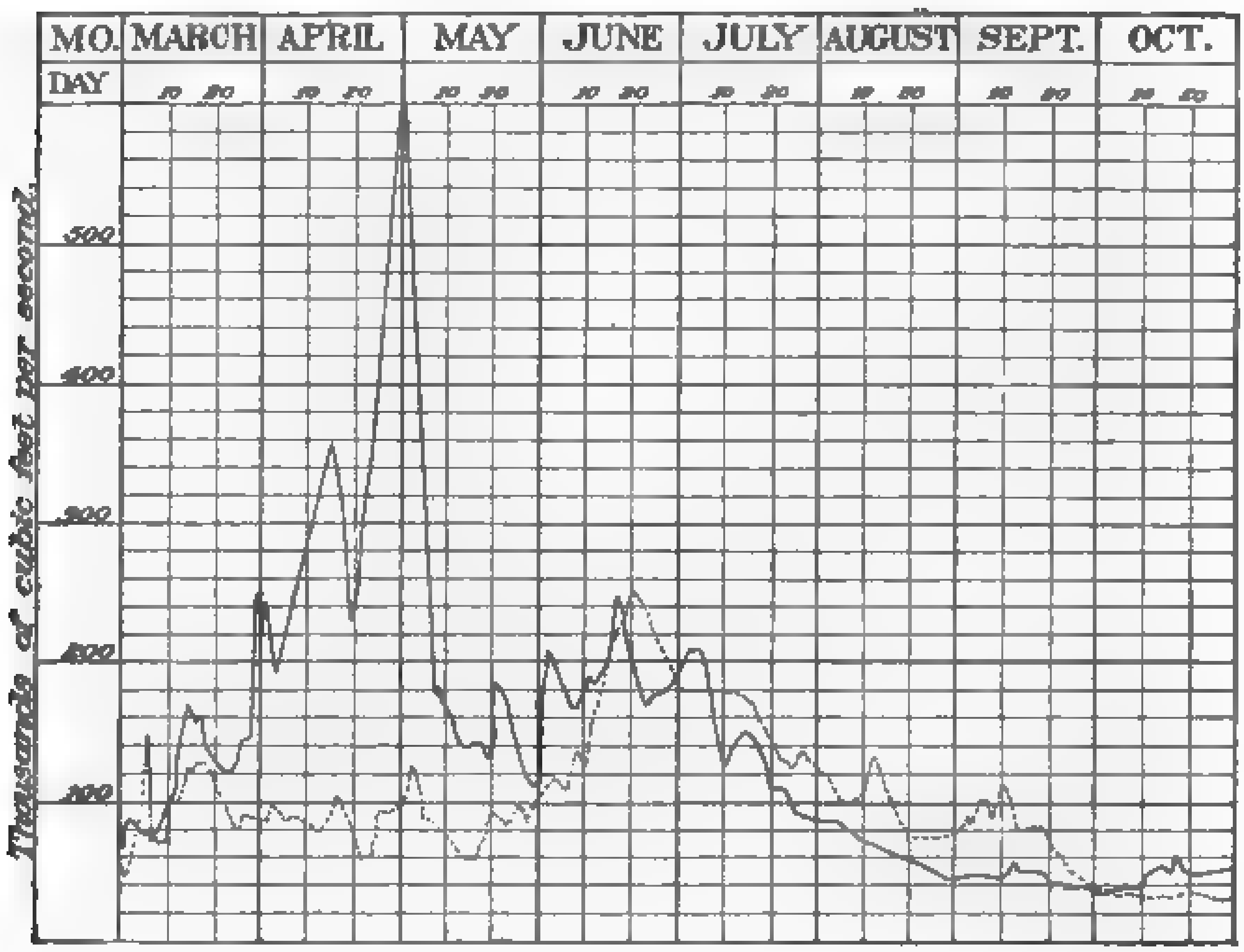

Fig. 1.—Discharge of the Missouri River at Kansas City, Mo., *for the irrigation seasons of 1881 and 1885.* Total run-off for irrigation season of 1881, 67,937,000 acre-feet, for season of 1885, 48,377,000 acre-feet. Full line shows discharge of 1881; dotted line, discharge of 1885.

national improvement in the construction of storage basins on the head waters of this river to protect people at the lower end of the river from floods, and to relieve those at the source from drought. This gives to the control of its waters a national interest and importance. But whether or not this be done, the mere diversion and use of the natural flow have already created property rights of immense present and far greater prospective value. There is no national or State law which so directly affects the success of the irrigator as that defining his right to water. Whoever owns a river practically owns the land it irrigates, no matter who holds the patent thereto, and the laws which define this *ownership* are the most important which any irrigated State is called *upon to enact.*

It is only in recent years that the ultimate importance of these questions has come to be realized. The first irrigation codes were devised to meet immediate needs and the evolution in each State has been much the same, although it has gone farther in some than in others. When the first settlers began the construction of ditches there were no laws governing water titles. The pioneer irrigator selected a location on a creek or rivulet where it could be cheaply controlled and built his ditch to reclaim the land it watered without making any record of his diversion or any claim for an appropriation. He recognized the need of filing on the land because past experience had shown him its value and the need of a definite title thereto; but all his past experience and his inherited prejudices were opposed to the ownership of water or any laws to regulate its control. The early users had all there was, and so long as the supply was ample one right was as good as another. But later other settlers came, and other ditches were built, until on many small streams the demand exceeded the supply. Whenever this condition arises there is need of a law to define and protect rights. Without it position counts for everything. The irrigator at the head of the stream takes whatever he chooses; those lower down take what is left. When the supply is exhausted they go without.

In no State have laws been enacted until someone's crops began to wither because of diversions above. Before any important laws were framed the questions to be settled had been complicated by a modification of the primitive appropriations. When the first rights were established the irrigator was, as a rule, the owner of both the ditch and the land it watered. He filed on the stream, diverted the water, transported it to the field, and used it on land he owned. But on larger streams the individual farmer can not do this. There great dams must be built and substantial head gates constructed to control the torrents which beat against them. The main canals stretch away for scores of miles, skirting cliffs and crossing ravines on flumes and trestles that require the highest engineering skill in their design and construction. The majority of the canals of this character have been built by capitalists who do not use the water diverted, but furnish it to others. When it comes to a determination of these rights, therefore, the question arises as to who is the appropriator. In whom does the right to the water inhere? Is it the owner of the canal which takes it from the stream, or the farmer who uses it on the land? There are other questions. How and when is an appropriation made, and what measures its amount? Is it by filing a claim, building a ditch, or beneficially using the supply? Is the volume measured by the quantity which canals or water ways will take from the stream, or by the volume which has been actually used? These are fundamental questions which every State must definitely answer before water rights become secure.

The right of each of these States to control the diversion of its streams is not the same. In the Northwest Territories streams are

declared to be the property of the Crown. In Wyoming both surface and subterranean water supplies are, by the constitution, made the property of the State. As this document was ratified by Congress, State ownership is a part of the compact between the State and General Government. The constitution of Colorado makes water public property. In the other States the right to enact laws on this question is based upon the act of Congress recognizing local laws and customs. In the Northwest Territories and in Montana, Wyoming, and Colorado riparian rights are abrogated. In South Dakota the question of their abrogation is now before the State supreme court.[1] Kansas is divided. West of the ninety-ninth meridian the doctrine of appropriation prevails. East of it riparian rights are recognized. The adoption of the common law in the Nebraska constitution makes riparian rights a part of the organic law of that State. The statutes, however, make the right to appropriate water as absolute as do the water laws of either Colorado or Wyoming, and the courts seem disposed so to restrict the rights of riparian proprietors as not to interfere with the use of water in irrigation. The importance of this question to that State and the need of all the available water supply in the reclamation of lands in the western half of it makes it desirable that this apparent conflict between the constitution and irrigation code be remedied at an early date.

In Colorado, Kansas, and the Northwest Territories rights for domestic purposes are superior to those for irrigation. It does not matter how early a right for irrigation is acquired, if the subsequent increase in population augments the demand for domestic purposes beyond the stream's discharge the earlier irrigation right may be destroyed thereby. In the other States those first in time are first in right. The holder of the first appropriation can take the volume to which he is entitled before any later rights are recognized. The holder of a second right is entitled to his appropriation from what remains, and so on in succession until the stream is entirely diverted. If there are any subsequent rights remaining, their holders go without. The value of an irrigated farm depends largely, therefore, on the priority number of its water right, or rather on the volume of superior rights.

WATER-RIGHT FILINGS.

Every working code of irrigation laws should provide for three things, and its success depends largely on the way this is done. These are:

(1) An accessible and trustworthy record of preliminary filings on streams.

(2) A clear definition of water rights and a simple, orderly, and inexpensive procedure for their determination.

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[1] Farwell *v.* The City of Sturgis.

(3) Some means of dividing streams in times of scarcity in order that the holders of prior rights may be protected.

Among the reasons for requiring a notice and record of proposed diversions are the following:

(1) They are needed as a protection to existing rights. Those who have built ditches and expended their labor and money in reclaiming land ought to be informed of each new ditch projected, because it may be so located, or of such dimensions, as to seriously diminish the common supply of water and work an injury to existing rights far greater than the benefit to the proposed builders. To prevent this, the notice should be of such character that all who desire to keep informed can do so, and they should have an opportunity to protest if the protection of existing rights makes this necessary.

(2) They are needed as a guide to settlers and to purchasers of irrigated farms.

The first thing an intending purchaser of irrigated land, or a settler on a farm which has to be irrigated, should do is to inform himself fully as to its title to water. The priority number of its appropriation and the number and location of other rights are all of the utmost importance, and it requires some knowledge of these facts to determine whether the paper title has any value, or whether the volume of superior claims makes it either a fiction or fraud.

(3) They are needed as a protection to those proposing to build new ditches or reclaim additional land.

The building of large canals and the settlement of the land under them takes time. It is not a matter of months but of years. It has taken over twenty years to settle the land under some of the canals along the Poudre River in Colorado, one of the foremost agricultural valleys of the West. The Development Canal in Wyoming was begun in 1883; in 1898 not one-half the land it waters is under cultivation. The Bear River Canal in Utah, the Dearborn Canal in Montana, the Gothenburgh Canal in Nebraska, and scores of others are all illustrations of the fact that the reclamation of arid land is slow and that one of the first things to be looked after is to protect those who begin this work from the danger of the creation of fraudulent or extravagant rights, by means of which an abundant water supply, which existed when a canal was begun, will have been absorbed before it was completed. This is no fancied danger or imaginary abuse. The loose methods of recording claims and the imperfect procedure for establishing rights which prevail in so many States makes ditch building on many streams one of the most hazardous forms of investment, when under proper laws it could be made one of the most secure. There are few rights for irrigation, even under the smallest ditches, which are perfected, through the actual beneficial use of water, in less than five years. There are many where a quarter of a century elapsed between the turning of the first furrow on the ditch and the moistening of some of the land it was built to reclaim. Every condition surrounding the

creation of a water right makes the need of an absolutely correct and definite statement of the purpose of the appropriation imperative. The time required to use the water and the fact that conflicting rights are being established elsewhere on the same stream at the same time, make it desirable that each claimant should describe his own project so certainly that no one else can contest his right because of changes, and that all others shall be equally specific in order that he may be fully informed, when he begins, of all the possible opposing rights which can be acquired. Without this, the temptation to exaggerate is too strong to be resisted.

It is the common experience of courts and boards of control that there is frequent disregard for the sanctity of an oath in proving up on a water claim, and the fact that many of these ditches are built in sparsely settled regions, where no one but the owner knows when work began or the rate of progress in construction, makes the temptation to advance the date or augment the capacity very great, when there is no official guide to memory or official check on the imagination. A recent experience of the Wyoming board of control will serve to illustrate this. In the determination of some rights to a small stream, acquired under Territorial laws, the claimants submitted proof of the date when ditches were built and water used. The stream was over-appropriated, the cutting of timber on the mountains having greatly lessened the water supply in recent years, so that the establishment of an early priority was of the utmost importance. One of the appropriators submitted a written sworn statement that he built his ditch in 1879. This was contested, and at the contest hearing he swore that he purchased the completed ditch in 1883. The records of the engineer's office show that a notice of this proposed ditch was filed in 1886. It was this official record which first disclosed the original error and which corrected the last one. Without this there is little doubt that the priority would have dated nine or ten years before the sod was broken.

A notice should fix the date when work will begin and when it is to end. It should do more than claim the stream; it should locate the ditch and describe every acre of land to be watered, and no change should be permitted without official record and approval thereof.

A record of the kind outlined can be secured only by subjecting the statements filed to an intelligent and rigid official supervision. Many of the parties desiring to build ditches know nothing of the irrigation laws nor of the measurement of the flow of streams or capacity of ditches. With the best intentions, therefore, they will make such mistakes as will destroy the authenticity of the record if all statements are recorded as filed. It is the experience of land officers that so simple a document as a homestead filing needs to be examined before being entered of record. Fully one-half of the "applications for permits" filed in the Wyoming State engineer's office have to be corrected in some detail before being recorded.

THE TWO SYSTEMS OF FILING CLAIMS TO WATER.

In the region drained by the Missouri there are two general systems of recording claims. Kansas and Montana have one, Wyoming, Nebraska, and the Northwest Territories the other. The system in Colorado is a compromise between these two, while the two Dakotas have no laws relative to this matter, the South Dakota law of 1881 not having been included in the amended laws. For convenience in discussion we will call the Kansas-Montana system the "first plan;" that of Wyoming, Nebraska, and the Canadian Territories the "second plan."

Under the first plan parties desiring to acquire rights must post a notice at a conspicuous place on the bank of the stream at or near where the headgate of the ditch is to be located, giving the volume of water claimed, the size of the ditch or canal which is to divert it, the date of the appropriation, and the name of the appropriator. In Montana this notice must subsequently be recorded in the office of the county clerk of the county where the ditch is situated. In Kansas the notice must be posted in the office of the county clerk and recorded in the office of the register of deeds of the county where the proposed headgate is to be located.

The second plan is based on the theory that streams are State property and the consent of the State authorities is necessary to any diversion and use thereof. This is the basis of the water laws of the Northwest Territories of Canada as well. Parties desiring to acquire a right must file an application for a permit. In acquiring rights for irrigation the application must be accompanied by a map of the ditch, a description of the land to be irrigated, and must state when work will begin and the time desired for completion. In Wyoming and Nebraska these applications are filed with the State engineer, who has to examine and secure their correction if not properly made out, and to reject them if they propose to divert a stream already appropriated or if the diversion is of a character detrimental to public interests. The approval of the permit fixes the conditions under which the right is acquired, and a compliance therewith is all that is needed to insure its establishment. Work can not begin, under these applications, until they have been approved by the State authorities. The procedure in Canada differs from the above only in detail. There the approval of the minister of the interior is required and a preliminary notice by publication in the Canada Gazette and in a local newspaper is necessary.

It will be seen that these two ways of making filings have nothing in common. Under the first the claims to one stream are often scattered in a half dozen places. Those to the Missouri in Montana are divided between fourteen counties. Under the second plan all the claims to a main stream and its tributaries are recorded in one office. The first plan is a claim of what is wanted. The second is a statement of what is to be done. Under the first plan there is no need to be care-

ful about the facts, because an indefinite claim will be recorded as readily as a specific one. The nature of the right established under the second depends upon its accuracy and it will not be recorded unless definite. Under the first plan there is no limit to the number of claims which may be filed nor to the volume of water which may be claimed. Under the second when the applications describe uses which will absorb a stream no more rights can be secured. Systems so different, applying not only to the same conditions but to the same streams, can not work equally well. One must be better than the other.

Wyoming irrigators file on the upper half of Sage Creek under one plan, and the Montana irrigators on the lower half under the other. An appropriator from the Republican River in Nebraska must file a map of his ditch and a description of the exact land it is to water, and he receives only a permit or license to reclaim that land and none other. Across the line, in Kansas, a man can file a claim to the same stream without a map or list of land, and it will be recorded if he claims more water than flows in the Missouri. It is worth while to know which of these two plans is based on right ideas and which has been justified by results.

The first plan requires intending appropriators to post notices on the bank of the stream. What is the object of these notices? Many hours have been devoted to this inquiry. The conclusion has always been that whatever service notices so located could possibly render can be much more effectively and surely arrived at in other ways. They are of no benefit to the proposed appropriator, because they give no definite right nor do they keep anyone else from posting other similar notices beside them if he so desires. They are of no service as a warning to appropriators elsewhere on the stream, because they do not and can not see them. To search for these notices along the two banks of the North Platte River in Wyoming would require a journey of a thousand miles. To look for them along the Yellowstone would require a longer journey. Even on lesser streams such a notice can serve no useful purpose. Who would think of traversing the banks of the Republican River for hundreds of miles hunting for location posts to find who proposed to appropriate its waters.

Not one irrigator in ten thousand ever sees or regards these notices. One newspaper notice would be more effective than a proclamation of this sort even if the post were a thousand feet high. No one can think of it as a part of the procedure in establishing a title to water without seeing how useless it is. Yet it is a feature of the water laws of more than half of the arid States. How, then, did it originate? The answer shows the strength of inherited ideas and what queer forms they assume. It was borrowed from the early custom of posting notices of land and mineral filings. The miner who makes a placer location posts a notice thereon telling the world what he claims. This is a reasonable and proper act, because anyone else desiring to file on the land will

examine it, and in doing so will see the notice. The notice is where it ought to be, and being there it also controls the land itself.

In like manner, settlers who located on unsurveyed land or in regions remote from land offices, asserted their right to possession by posting a notice describing the boundaries of the land claimed. Under existing conditions this action was necessary and effective, since the location and character of the warning enabled all who had need to know of it to see the notice. It is otherwise with a claim to a river which rises in mountains above and flows on to users of its waters miles below. Every user of its waters is affected by what takes place in either direction. The farmer or miner who either seeks to protect himself or inform others by posting a notice in some lonesome bend simply wastes his time.

Inherited ideas are queer things. They have done more than to perpetuate a meaningless procedure in water-right filings; they are the source of some exceedingly mischievous statements in the notices as recorded.

When the early homesteader made his land location his notice declared to all the world that he had a valid right to the exclusive occupation, possession, and enjoyment of the land located upon, together with all the hereditaments and appurtenances thereunto belonging or in anywise appertaining. This was correct. He did have exclusive ownership; but when he posts a notice on a river bank stating that he has the exclusive right to the possession or enjoyment of its waters, when the stream is already plastered over with other claims of the same nature, he only deceives himself when he thinks the declaration has any force.

The legal notices in use in Montana are intended to be posted and recorded before construction begins, and as a rule they are so posted and recorded; yet many of them contain this declaration:

> That John Brown does hereby publish and declare, as a legal notice to all the world, that he has a legal right to the use, possession, and control of and claims ——— inches of water of ——— ——— for irrigation and other purposes.

And further along this notice states—

> that he *appropriated and took* said water, * * * together with all and singular the hereditaments and appurtenances thereunto belonging or appertaining or to accrue to the same.

It will be observed that the idea or purpose of acquiring absolute personal ownership which exists in all mineral locations is applied, at least so far as the statement is concerned, to the filings on rivers. If the language of these notices is to be construed literally, it is not by the building of ditches or the applying of water to beneficial use that the right thereto is acquired, but by posting this notice on the bank of the stream and recording a copy of the same in the county clerk's office.

It does not need any argument to show that such a law would be so repugnant to common sense and detrimental to the public welfare that it never could be carried into effect. The use of these misleading expressions has been in the past and is destined to be in the future the cause of litigation and controversies, the ill effects of which can scarcely be estimated. Before this discussion is completed it will be shown that not only do irrigators think that the filing of these claims gives them the ownership of whatever volume they describe, but that courts in adjudications have upheld that view, and that scores of streams have been disposed of through the recognition of rights which had nothing more substantial than this claim to support them.

EXCESSIVE CLAIMS FOR WATER.

In the later discussion of the Montana law the filings on one stream are given (p. 55). It is not an exceptional case. The claims on scores of other streams were equally numerous and equally liberal. In examining the filings on one stream it was noticed that the claims varied in volume from 1 to 5 second-feet, until one claimant, more expansive in his ideas than those who had preceded him, claimed 300 second-feet. This was more than twice the stream's discharge, but every claim which followed—ten in all—was for 300 second-feet. This disposition to claim everything in sight extends throughout the irrigated area. It is not restricted to the Missouri, as the following facts from the record in another river basin show. The Boise River, when gauged in September, 1898, showed a discharge of 698 second-feet, or 34,900 statute inches. The official records of one of the three counties through which this river flows show 151 claims for water from this stream, amounting in the aggregate to 6,361,800 inches. Thus, with less than 35,000 inches in the stream at its lowest stage when measured and with probably not to exceed fifty times that discharge at the flood season, we have here claims to 6,361,800 inches, with all the hereditaments and appurtenances thereunto belonging or in anywise appertaining, and this without including the claims of the county above or the county below.

A land system which would accept a score of filings for the same quarter section and then leave the settlers to fight for its possession in the courts would not be held in high esteem. A water-right law which places no restrictions on the claims to streams is just as illogical and as fraught with needless abuses. To say the least, these records are of little or no value. They are worse. They are a makeshift which misleads and deceives everyone who relies on them. No worse element can be introduced into a working code of laws.

Wyoming and Nebraska began with a filing law similar to those of Montana and Kansas. Experience showed that reform was necessary. It was not alone the fact that the record was both inaccessible and unreliable. This was bad enough, but the more serious objection was

that filing did no good. There was no way to stop filing claims when the stream was exhausted. There was no way to tell what claims were followed by construction and what not. There was no way to cancel and get rid of those which began and ended with the filing. There was no way to protect actual users when the supply ran short. In brief, it was not a working plan.

Whenever users needed protection they had to go to the courts, and when they did this the county record became one of two things: Either rubbish or a menace to a just settlement. Wyoming's experience showed it could be both. Litigation to settle the rights on Crow Creek was begun while this law was in force, and each claimant brought into court his water claim duly recorded with the county clerk as evidence of title to water. The court accepted it as reasonable and conclusive. As a result, rights to 485 second-feet were decreed out of a creek which seldom carries over 10 second-feet and of which the normal flow is but little over 5 second-feet. Not one acre in ten for which claims were filed had ever been watered. Many of the ditches had not then and have not since taken a drop of water from the creek. So far as diversion and use were concerned, many were wholly without foundation. A right would have been just as valid if its holders had simply looked at the creek and then filed an "appropriation" with the clerk.

The excess decreed was not, however, so remarkable as its division among the claimants. The actual need for water on the land along this creek is small. One second-foot will on an average furnish all the water needed to irrigate 100 acres of land, but in making their claims these irrigators were generous. The second appropriator claimed 6.92 second-feet for 100 acres and got it in the decree. The next claimed 23 second-feet for 200 acres and that was decreed. The fourth claimed 11.36 second-feet for 28 acres; that was enough to cover it about 300 feet deep in a year; but the court was as liberal as the claimant and it was decreed. One appropriator was decreed 37.5 second-feet for 200 acres, while a less fortunate one obtained only 29.8 second-feet for 5,000 acres. One appropriator was allowed 31.9 second-feet for 200 acres, while the succeeding one obtained only 10.98 second-feet for 1,620 acres, or about one-third the water for eight times the land. A recital of the entire decree would be a repetition of these incongruities, which had their origin in treating these claims as vested rights.

When rights began to be based on the volume actually used, those for irrigation being determined by the acres watered, the difference between the claim and the volume allotted always led to one of two conclusions on the part of the irrigator: That the original filing or the later adjudication was a fraud. The two following examples, taken from the Wyoming records, show why they were seldom in accord and how radical was the encroachment on what was regarded as a vested right.

Notice to the public and to whom it may concern.

All persons are hereby notified that the undersigned hereby gives notice that he claims for his own use and benefit all the water flowing within the banks of Wagon Hound Creek through his premises, the same being his ranch and range, for the use of irrigation and agricultural purposes from and above the point where the notice is located until said waters are passed by any lands he may claim or own.

There were already eight claims to that stream when the above was filed, three being for a larger volume than was granted to all when an adjudication based on actual use was had.

On Savery Creek three ditches were built prior to 1881 and the water actually used. In 1882 the following claim was filed:

To all whom it may concern.

Know ye, that I, ——— ———, have, on the 26th day of August, 1882, located and do hereby claim all the water above this notice for irrigation purposes, said ditch commencing at this notice and running in a southwesterly course to section 22, township 13, range 89, for which I do claim all rights and privileges under the United States irrigation laws.

To recognize a claim of this character when these rights were determined was out of the question. There were fifteen other ditches all using water, yet, as in the case before cited, this irrigator had for fifteen years believed that he was the owner of all the water in the stream, and he also believed that to set this aside was an unwarranted and unjust interference with his vested rights.

Where laws mislead or fail to direct, as these do, there need be no surprise that litigation follows. The only wonder is that irrigators who have to deal with such uncertainties are content to settle their differences in so peaceable a fashion.

PERMITS TO APPROPRIATE WATER.

The laws which provide for filing under the second plan are all of recent enactment. They are, therefore, based on ample experience of "how not to do it."

The first change to be noted is that the filing is not a claim to ownership of the stream or any part of it. It is an application for license or permit to divert and use the public water supply. Instead of a claim for a specific volume of water, the purpose of this filing is to accurately describe the proposed use. With applications for irrigation rights there must be a map of the ditch and a description of the land to be reclaimed. Land not described acquires no rights. An imperfectly prepared map simply delays approval. Applicants soon learn the need of accuracy and care, and with this knowledge comes confidence in the law which requires it. The notice to other users is best provided for in the Canadian law. This requires publication by the applicant in a local newspaper, and in the Canadian Gazette, of the intention to apply, and publication of a notice by the Government of its approval of the application. Compare this sort of notice to other appropriators with a placard

on a post in some lonesome bend of a willow-bordered stream. These applications have to be examined and approved by an official who is giving his entire time to the management of the public water supply, who has before him every other filing on the stream, and who either knows the conditions or can and must inform himself regarding the results to follow the approval or rejection of the application. The approval fixes the conditions under which the right is acquired, the engineer's certificate in Wyoming being as follows:

THE STATE OF WYOMING, *State Engineer's Office, ss:*

This is to certify that I have examined the foregoing application and do hereby grant the same, subject to the following limitations and conditions:

Construction of proposed work shall begin within one year from date of approval.

The time for completing the work shall terminate on December 31, 18—.

The time for completing the appropriation of water for beneficial use shall terminate on December 31, 18—.

The amount of the appropriation shall be limited to 1 cubic foot per second of time for each 70 acres of land reclaimed on or before December 31, 18—, and the additional volume used for ——— ——— purposes on or before said date.

Witness my hand this —— day of ———, A. D. 18—.

——— ———,
State Engineer.

No other permit to water the land described will be issued without a hearing and good cause therefor being shown. There is no uncertainty about priorities or the volume of prior appropriation. The record in the engineer's office at any time is as conclusive as to both matters as is the record of the Land Office of the filings on public land. Filings may be abandoned or they may be canceled. The later rights may be improved, they can not be impaired.

The difference does not end with the filing; it continues in the subsequent treatment of these records. The first plan requires work to begin within sixty or ninety days, but it is made nobody's business to ascertain whether or not it does begin, and a claim can not be canceled if it does not begin for sixty years. Under the second plan, reports of progress must be made and where a license or permit is not followed by work the permit is canceled. In this way the unappropriated volume is at all times apparent.

The value of this plan is shown by the constant use made of the filing records. There is not a day in which those of Wyoming are not consulted by land owners, ditch builders, or water users, and the same is probably true of the other States. The contrast between the convenience of having all the rights to a stream and its tributaries brought together and the expense of their examination when scattered in the various counties is so great that none of the States which have adopted the second plan regret the additional expense or consider a return to the primitive system.

FIXING OF PRIORITIES AND AMOUNTS OF WATER RIGHTS.

Parties who file on public lands must later prove up—that is, show that they have complied with the land laws. Parties who file on streams must also sooner or later prove up—that is, establish the priority and amount of their right. The proof required in land filings is in every case the same. If a homestead, it must be shown that the land has been lived on; if a desert, it must be shown that it has been irrigated. The proof in water-right filings depends on the State where the ditch is built. The priority of a ditch on the Laramie River in Colorado is established by a lawsuit in the district court. The priority of a ditch on the same stream, a mile below in Wyoming, is established by proofs filed with the State board of control. The title to public land, when established, is the same in each of these States; the title to water in a stream depends on which side of a State boundary it is acquired. In the Northwest Territories the amount of the right is governed by the size of the ditch. It used to be so in Colorado, Nebraska, and Wyoming. Experience has shown the need of reform in that matter. At present in Nebraska, Colorado, Wyoming, and Kansas, in order to acquire a right the water must have been actually used, and it is the volume so used, not the volume which can be diverted, which determines the amount of the appropriation.

The difference in the methods of making filings is succeeded by an equally striking difference in the methods of establishing the priority and amount of the right.

In Wyoming and Nebraska the permit that is issued for the diversion and use of a stream gives certain conditions which, if complied with, fix the amount of the right. One of these conditions is the date when the ditch or canal must be completed, and the date when the beneficial use of the water must be completed. When this has been done parties file a notice of such completion with the State engineer. This is followed by an official examination and measurement of the ditch and the land reclaimed, the results of which are embodied in a report filed in the engineer's office. The appropriator is also required to file a sworn statement of completion of the ditch and of the irrigation of the land and the acreage which has been irrigated. If the report of a special examiner and the sworn proof of compliance with the permit made by the appropriator agree with each other and with the original permit, a certificate of appropriation of water is issued by the State board of control, which is a title from the State to the right to use the stream, as a patent to land from the Government is a title to its ownership. The priority of the right is governed by the date when the application was filed, and the volume in rights for irrigation by the need of the land described. It will be seen that this procedure follows closely that of the General Government in disposing of land. The forms of proofs are all printed. There is no wholesale disposal of a stream in one adjudication. Each right is settled by itself, applica-

tion to use being promptly followed by issuance of title to the right. The issuance of the certificate of appropriation is simply a ministerial, not a judicial, act. There is a special importance in this, because the opinion prevails in many States that it is impossible to devise an irrigation system by which rights can be established in any way except by a judicial decree.

The procedure in the Northwest Territories is the same as in Wyoming and Nebraska, except that the essential fact required to be established is the construction of the ditch. Its size and capacity govern the extent of the right. The names of the irrigation officials who pass upon these matters there are also different.

In Colorado proving up is accomplished through an equitable procedure in the district court. An elaborate statute fixes all the details of this procedure from the notices of appropriators to the final rendering of a decree. It is cumbersome and expensive to appropriators, and is seldom resorted to for the establishment of a single priority. The usual practice is to delay their settlement until a large number of claims have been inaugurated, when they are all determined at once in an omnibus adjudication. The decree which fixes these priorities is filed with the State engineer, and becomes his guide in the division of water among users.

The laws of the Dakotas make no provision whatever for the determination of these rights. The laws of Montana and of Kansas make the district court the tribunal for the settlement of these questions when controversies arise, but neither of the laws defines the way notices shall be given nor provides for the record or enforcement of the decree when rendered, as does that of Colorado.

As in the matter of filings, not all of these laws can work equally well. They apply to the water of the same river, to rights which are used during the same seasons of the year, for the cultivation of the same kinds of crops, and under very similar conditions. Some have been in operation for a quarter of a century, and all for a period long enough to determine their relative efficiency. If one is better than the other, or if experience has shown that certain features of any one are worthy of adoption, it is of the utmost importance that advantage be taken of this fact. The need of a uniform system in fixing the priorities is too obvious to need discussion.

THE WYOMING AND NEBRASKA LAWS.

The Wyoming and Nebraska laws possess the following merits:

(1) The prompt determination of rights. In those States as soon as an irrigator has complied with the law he is in a position to obtain its benefits. The facts on which the appropriation is based are taken at the time the work is done. In this way one of the great sources of controversy—delay until many of those who know the facts have died or moved away—is avoided.

(2) Cheapness to the appropriator. In States where water rights are established by court procedure every appropriator has to employ a lawyer. He has to incur the expense of himself and his witnesses in presenting his testimony to the court. In Wyoming and Nebraska the testimony is prepared on a blank form and is sworn to before a member of the board of control. The examination of the lands irrigated and the ditch which diverts the water is made by the State. There is no greater need of legal advice in preparing this proof than there is in submitting proof in a land office. The entire indispensable expense in proving up on a water right in Wyoming is $1 for the issuance of the certificate of appropriation by the State engineer and 75 cents for its record in the county clerk's office.

Another important consideration relates to provisions for a final settlement of water rights. In Colorado, Nebraska, and Wyoming there is a statutory period, after rights are determined, during which their validity may be contested in the courts, but after it has expired they become absolute. In some of the other States litigation over these questions may be perpetual.

The remaining question to be considered is which of these methods comes nearest determining the actual facts and has done most to protect the rights of actual users. This is the important question. Delay and expense are of little moment if they result in a better settlement of these rights which will, from year to year, become more valuable and important.

In considering this it is significant that Wyoming and Nebraska are conspicuous for the absence of water-right litigation. There is provision for appeal to the courts at every step, from the approval of a permit to the fixing of the priority in the final certificate, but appeals are not taken. As the years go on what was at first regarded by many as a hazardous innovation is now firmly established in the confidence of water users. The State board of control is in no more danger of being abolished than the State supreme court. A result like this, following a change from all previous systems, is a substantial evidence of the efficiency of the new system.

There are many reasons why the determination of rights under the procedure outlined should be more satisfactory than by a court decree. The facts to be established are physical, not legal. Under the laws of each of these States the priority is fixed by the date of the permit. The facts to be determined are the acres irrigated and the volume of water needed by those acres; and the most direct and certain way to do that is to go on the ground and measure the ditch and the land watered. The surest way to obtain the length of a city lot is to measure it. To obtain the weight of a load of coal we put it on the scales. It does not require a court decree nor the exercise of judicial powers to establish the fact of residence on a homestead or the irrigation of a desert filing. Under a rational code of laws there is no need whatever to file

complicated pleadings in court to determine how many acres of land have been watered or how many miles of ditch built. It is undoubtedly true that the haphazard system of filing claims in some States makes the services of the courts necessary, but this does not insure a satisfactory settlement of rights. On the contrary, it simply requires judges to do the best they can to repair the consequences of previous mismanagement and neglect.

The officials of Wyoming and Nebraska are in an infinitely better position to make a just determination of irrigators' rights than are the courts in the other States. They examined the original filings; they are familiar with the stream and with all the facts relating to other rights; they have measured the water supply and the land reclaimed. When it comes to passing upon the proof of use they have not only the facts of the special examiner but a special familiarity, based on experience in other cases, with the conditions on the stream.

COURT ADJUDICATIONS.

In States where the courts determine these rights they have to act without personal experience and to rely too often on conflicting, indefinite, and interested testimony. Courts have no reason to become specially informed concerning irrigation problems along any stream, with the water supply of the stream, or to know from personal examination anything of the physical facts on which a just determination of these rights must in large measure depend. Their decisions have to be based upon the pleading of attorneys and the testimony of witnesses. Here again is a difference which operates against a satisfactory settlement by means of court decrees. In Wyoming and Nebraska the fundamental idea in the establishment of a water right is that it is a disposal of public property and that public interests are to be first considered. Hence, the examination is made by a State officer who has no personal interest in the right. There is not a State in which these rights are settled in court that provides for the gauging of streams, the measurement of ditches, or land reclaimed by a disinterested public official as a guide to the court in determining the facts. Even in Colorado, with its admirable administrative laws, there is no provision for giving the courts the benefits of the State engineer's experience and knowledge of physical conditions. All court proceedings for the determination of rights to the public water supply are simply and solely contests between private interests where each man wishes to acquire all he can for himself and to do all he can to cut down the allotment to others.

That is the situation regarding court decrees where there is a genuine trial of rights, but it has sometimes happened that these adjudications have been instituted for the sole purpose of acquiring control of a stream in accordance with a division agreed upon beforehand. Such proceedings, no matter what the intent of those in charge, have resulted in gross frauds and injustice to those who actually used the water. In

such cases the contest is one only in name. Whenever appropriators agree among themselves regarding the amount of water they will claim, they can usually secure a decree for the full amount. It is extravagant decrees secured in this way which now are so serious a menace to the rights of users on many streams.

The danger of this was not at first appreciated, but its consequences are now becoming apparent. Judge Victor A. Elliott, who presided over the most important adjudications in northern Colorado, in discussing this in a brief recently filed in the Colorado supreme court in favor of a rehearing and readjudication on one of these streams, thus characterizes both the law providing for court decrees and the decrees themselves:

Prior to the passage of the irrigation acts of 1879 and 1881 this State was sparsely inhabited—not nearly all of our agricultural lands had been brought under cultivation by means of irrigation—and there had been very few controversies respecting priorities of right to the use of water for irrigation purposes.

When any such controversy did arise, it was merely between a few, perhaps not more than two rival claimants, and the rights of such claimants were litigated as in ordinary lawsuits. Each party was well advised as to the claims of the other, and so was prepared to assert his own claim and contest that of his adversary by all legitimate evidence under the law by the aid of legal counsel.

But our people felt that such proceedings for settling the rights to the use of water were too slow, and that many irrigating seasons would pass and many crops be lost before litigants could secure their rights.

Hence the irrigation acts of 1879 and 1881 were passed. The design of these acts was to secure a summary adjudication of water priorities on an extensive scale.

The acts contemplated the promulgation of decrees which could be summarily enforced by the water commissioners, without waiting for an appeal to the courts when a controversy should arise.

The effect of these irrigation acts was not foreseen by the great mass of the people whose most valuable rights were to be affected by them. The agricultural classes are generally the slowest people to take notice of legislative acts affecting their interests.

The result of these irrigation acts was to precipitate legal proceedings upon large numbers of people, and thus make it necessary for them to assert and defend their rights as against their neighbors, when, in fact, their rights had never been assailed or questioned.

By the express terms of these acts a single claimant to water rights could compel every other claimant in the water district (hundreds there might be) to come into court and assert his claims and defend against the counterclaims of all the rest, and this though there had never before been any controversy in respect to such claims.

Under such circumstances it is not strange that very little attention was given by most of our farmers and ditch owners to the adjudication of water priorities. Many of them seemed to regard the proceedings as altogether amicable, and hence took no pains to guard against the overreaching of the few, whereas, in fact, no proceeding could have been devised which would have been more adverse in character or which should have been guarded with more jealous care.

As we have before said: "In the earlier adjudication of priorities, under the acts of 1879 and 1881, there was little or no contention between rival claimants to priorities. People seemed to think all they needed to do was to prove up their appropriation and get decrees for as large quantities of water as possible—evidently thinking the court had the power to make the natural streams yield the amount of water *thus decreed at all times*, irrespective of senior decrees of priority, and notwith-

standing the fact that the amount of the appropriations decreed from some of our natural streams was four times as much as the ordinary flow of the water of such streams."

Aside from the question of procedure, there is a difference in the nature of the right conferred by the laws of Wyoming and Nebraska and that conferred in some of the States where these rights are determined by court decrees. In the first-named States rights for irrigation attach to the land. The certificate of appropriation described the land where the right was acquired, and to which it is attached. The right is for enough water to irrigate it, not to exceed a prescribed maximum. The acreage of this land can not be expanded; in fact, the tendency is for the demand to diminish as the soil becomes moistened and irrigators become more experienced. But in many of the States the rights decreed are for a continuous flow of a designated volume regardless of the place or kind of use. Where water is attached to the land there is no incentive to claim an augmented volume. All that can be had is enough to produce crops, and that volume is determined by the acres rather than by the maximum volume allowed. But in the second case the tendency to exaggerate the right and to obtain as large an allotment as possible is very great. Where water is personal property, if the party securing the right does not use it, he can sell it or rent it to some one who needs it and is willing to pay for it. Hence adjudications are often not so much for the protection of actual users as a struggle to obtain speculative control of streams. Not having the benefit of expert and disinterested advisers, the findings of the court often lead to peculiar complications. In a decree examined by the author a ditch watering 9 acres of land is given water enough to cover that land to a depth of 536 feet in a year. In the same decree a ditch watering 2,000 acres is allowed 5 cubic feet, while a ditch watering 200 acres has a grant of 20 cubic feet; that is, 1 acre under the last ditch is allotted as much water as 40 acres under the first.

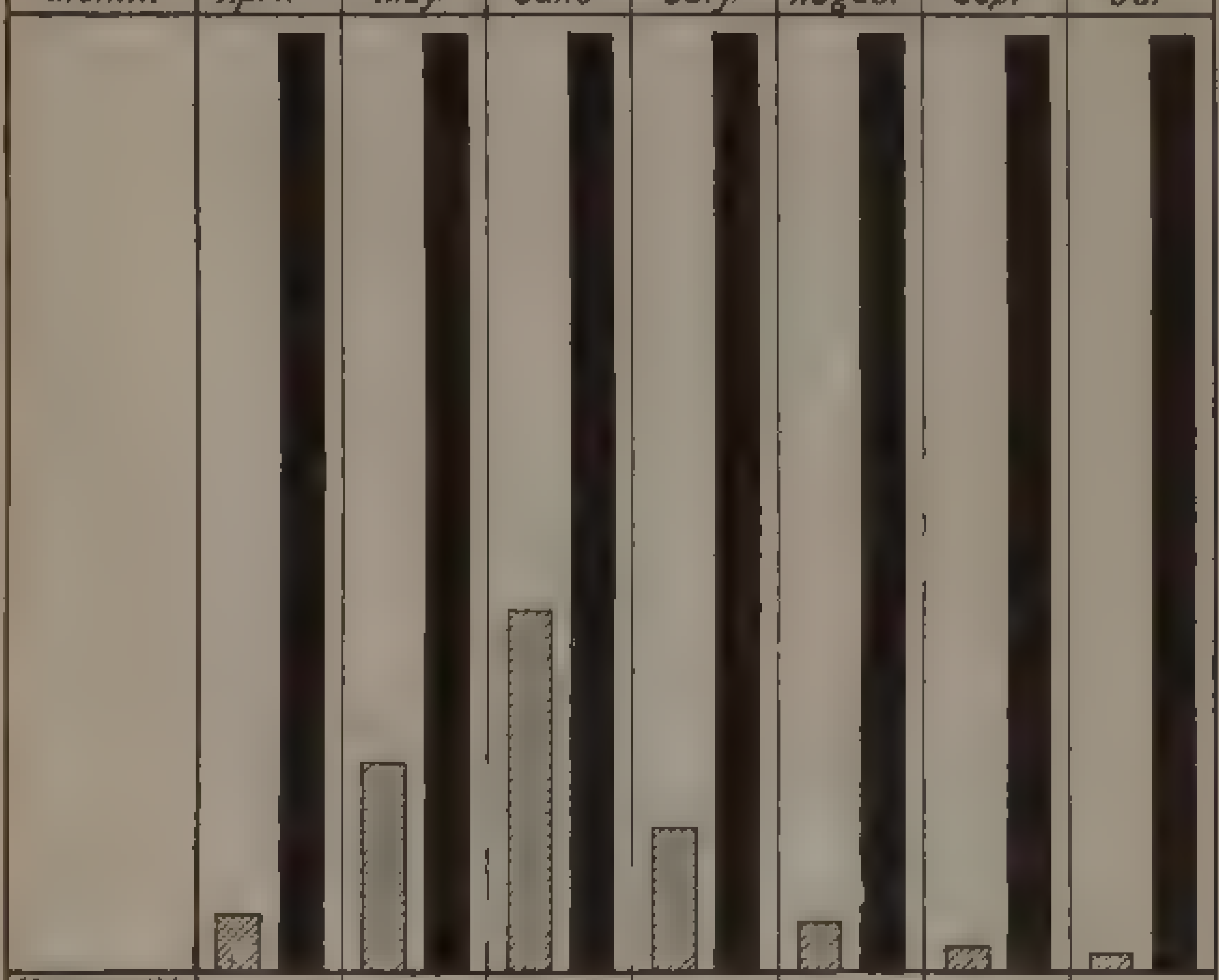
In 1884 and 1885, while acting as assistant State engineer of Colorado, I measured the ditches of northern Colorado on the streams which had been previously adjudicated. My report of these measurements called attention to the discrepancy between the decreed appropriations and the actual carrying capacity of these ditches and canals in the following terms:

> So great was this in some instances that the result of the gaugings and the decreed capacity seemed to have no connection with each other. Ditches were met with having decreed capacities of two, three, and even five times the volume they were capable of carrying, ever have carried, or will probably ever need. Other ditches in the same district have decrees which fairly represent their actual needs. It needs no argument to show the worse than uselessness of these decrees as a guide to the water commissioner in the performance of his duties.

When these decrees were rendered the majority of appropriators believed that rights for irrigation were limited to the lands already irrigated, and that, so long as used there, the actual volume stated in the

decree cut very little figure. Hence there was little solicitude on the part of late appropriators as to any danger arising out of excessive grants. Under the terms of these decrees each appropriator is entitled to a definite volume of water, described in cubic feet per second, and to a continuous flow of this volume throughout the year.

Recent decisions have recognized the right of the holders of these decreed appropriations to sell the entire volume granted. As a result,



Month.	April	May	June	July	August	Sept	Oct
Mean monthly Discharge, 1890 to 1894.	279	1012	1714	675	239	115	96
Volume of Excess Appropriation.	4354	3621	2919	3958	4394	4518	4537
Number of Appropriators without right to water.	91	63	50	70	93	98	98

Total volume appropriated 4632.53 sec.-ft
Total number of Appropriators 104.
Mean monthly discharge

FIG. 2.—Relation between the mean monthly discharge of the Poudre River and the appropriations therefrom

the owners of earlier priorities are enlarging their ditches and extending them to other lands, or, where this is not possible, are attempting to dispose of the surplus to other users. Every attempt to do this, however, is contested. The truth is that irrigators have, in practice, been building up a system on one theory of water rights while the courts have rendered a number of decisions based on another theory. We have now reached a point where one of the two must give way.

If the doctrine laid down in these decisions is carried to its logical conclusion it will transfer the ownership of a majority of the streams of northern Colorado to a few early appropriators, and compel a large proportion of the actual users of water to purchase from such appropriators the water they have heretofore had for nothing. That this is not an extreme statement is shown by the accompanying diagram (fig. 2), which exhibits the relation between the mean monthly discharge and the decreed appropriations of the Poudre River.

The last examination of the records showed there were 104 appropriators from this river, the aggregate of these rights being 4,632 second-feet, each right being for a continuous discharge of the volume decreed; yet in August of 1894 the stream carried only 162 cubic feet per second; in August, 1893, 141 second-feet; and the stream has frequently fallen during the irrigation season to below 100 second-feet. If the holders of these rights had lived up to their opportunities during the last half of every irrigation season, fully one-half of the actual users of water would have had to buy from the holders of these excess rights every gallon of water used after the middle of August. That they have not been compelled to do this is due to the fact that irrigation practice in that State is superior to irrigation law.

The appreciation of the dangers which this situation creates is not confined to farmers alone. In a different brief from the one before referred to it is thus forcibly stated by Judge Elliott:

> Excess priority decrees are a crying evil in this State. From every quarter the demand for their correction is strong and loud. Such crying demand can not be silenced by declaring that the meaning and effect of such decrees can never be inquired into, construed, or corrected after four years.
>
> In many cases such decrees are so uncertain, so ambiguous, so inequitable, so unjust, and their continuance is such a hardship that litigated cases will be continually pressed upon the attention of the courts until such controversies are heard and settled, and settled right. Litigation in a free country can never end while wrongs are unrighted.

It was not until the holders of these excessive rights began to make use of them for speculative purposes that farmers realized the danger which menaced them. It is more apparent in Colorado than in any other of the arid States herein discussed, because irrigation has made greater advances in that State than in any of the others. Streams are more nearly appropriated and water is more valuable, but the conditions under the Colorado laws are far less dangerous than they are under the laws of many other States, and an equal development in those States will show equally serious abuses. What these are is well stated in a brief recently filed in the Colorado supreme court by the Hon. Platt Rogers, of which the following is an extract:

> We have reached a stage in the history of irrigation development at which it is found highly profitable to the owners of the older appropriations to avail themselves of the rights said to be theirs by the opinions heretofore rendered by this court in the reclamation of new lands. The era of "disappropriation" has fairly set in, and as an injustice will not be submitted to until, by repeated decisions, it is

made manifest there is no hope, we are promised a fresh crop of litigation to prevent the enforcement of decrees that, under the construction placed upon them, lead not to peace but to war. * * * It will, moreover, bring to pass a great wrong, foreseen by John L. Armstrong, one of the witnesses in this case, who, in his report as water commissioner to the State engineer (as published in 1887), said "that by reason of the unjust decrees of the court, whereby greater quantities of water were decreed to ditches than the ditches would carry, it is possible, after ten or fifteen years, for these ditches to enlarge and bring under cultivation land never before irrigated, at the expense of those ditches which have actually used the water for many years for irrigation."

All of the districts in the northern part of the State have decrees similar to those mentioned by Mr. Armstrong. The reports of the State engineers exhibit this anomalous condition in graphic form. We are not, therefore, called upon to treat a sporadic case, but to deal with a prevailing condition. * * *

The decrees, in their entirety, are falsehoods, and universally accepted as such. They furnish a fresh illustration of the truism that "a lie never ceases to do evil." If the construction heretofore placed upon them, in some cases, is to prevail, we

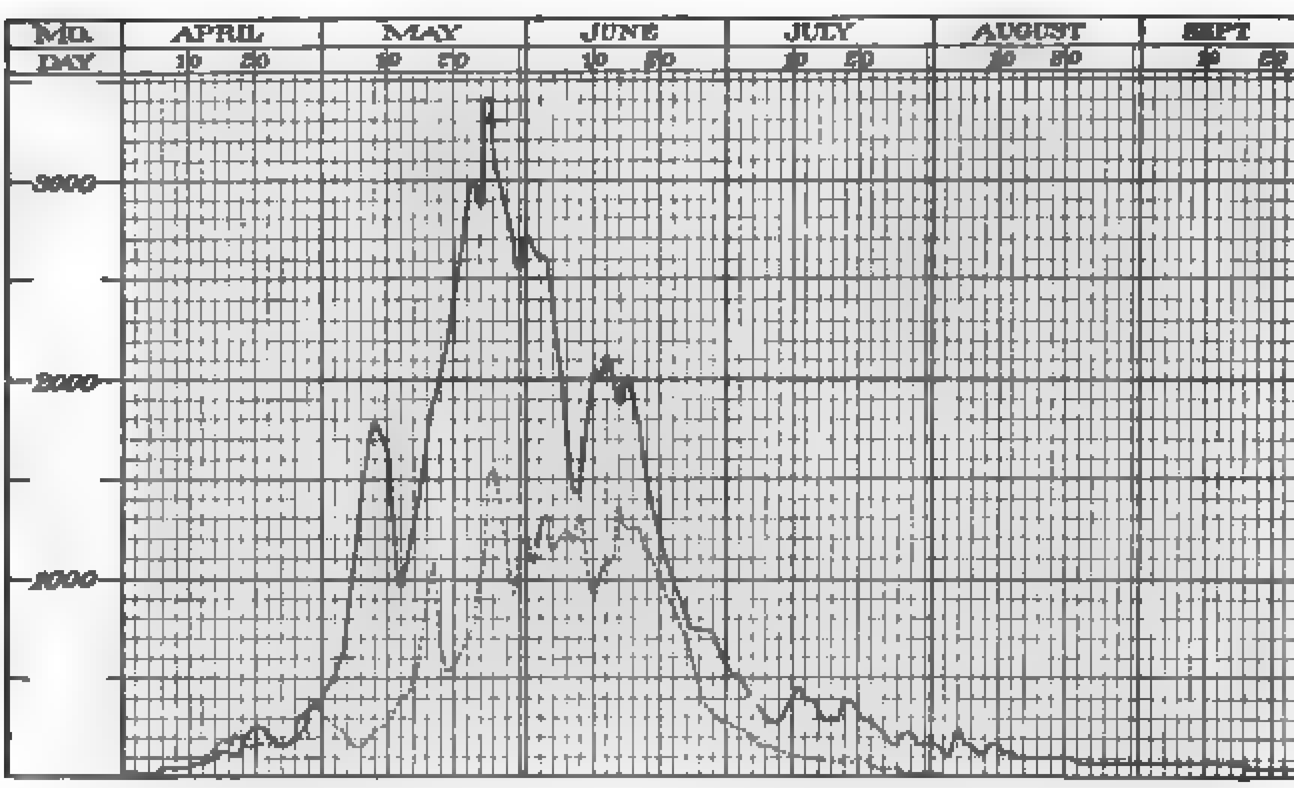


FIG. 3. Discharge in second feet of Laramie River at Woods, Wyoming, in 1897. The full line shows discharge for 1897, the broken line that for 1898. Total discharge for season of 1897, 246,000 acre-feet; for season of 1898, 111,000 acre-feet.

have legalized a method of accomplishing the precise thing the constitution intended to prevent, viz, speculation in water. If this court will avail itself of those matters of public history which ought to be within its cognizance, it will learn that decreed appropriations are now being bought, not merely to utilize the volume heretofore diverted and used, but to obtain the advantage of the full amount decreed, for speculative purposes.

There are two objections to making appropriations for irrigation a right to a perpetual flow of any definite volume of water. Such rights do not conform to the necessities of users or to the fluctuations in the flow of streams. No irrigator uses water all the time. In the States under consideration he does not use it one-half the time. Even during the irrigation season the use is intermittent, and much greater in some months than in others. The holder of a right to a continuous flow not needing it during the greater part of the year is continuously tempted

to convert it into a speculative commodity by selling the surplus. The diagram (fig. 3), showing the discharge in second feet of the Laramie River, is a typical example both of the fluctuation in the volume of streams during the irrigation season and of their variation in discharge from year to year. It will be observed that in 1897 the maximum dis-

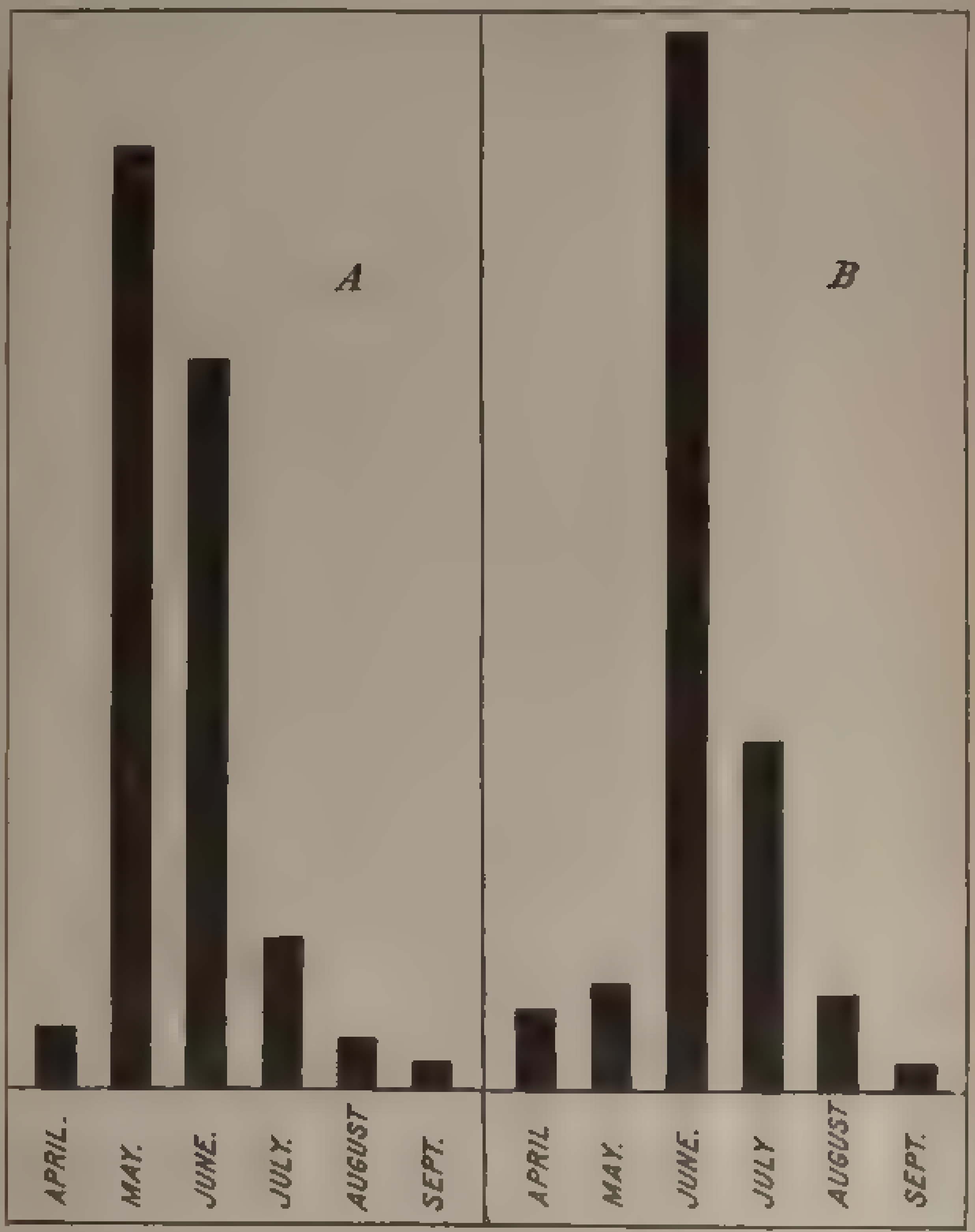
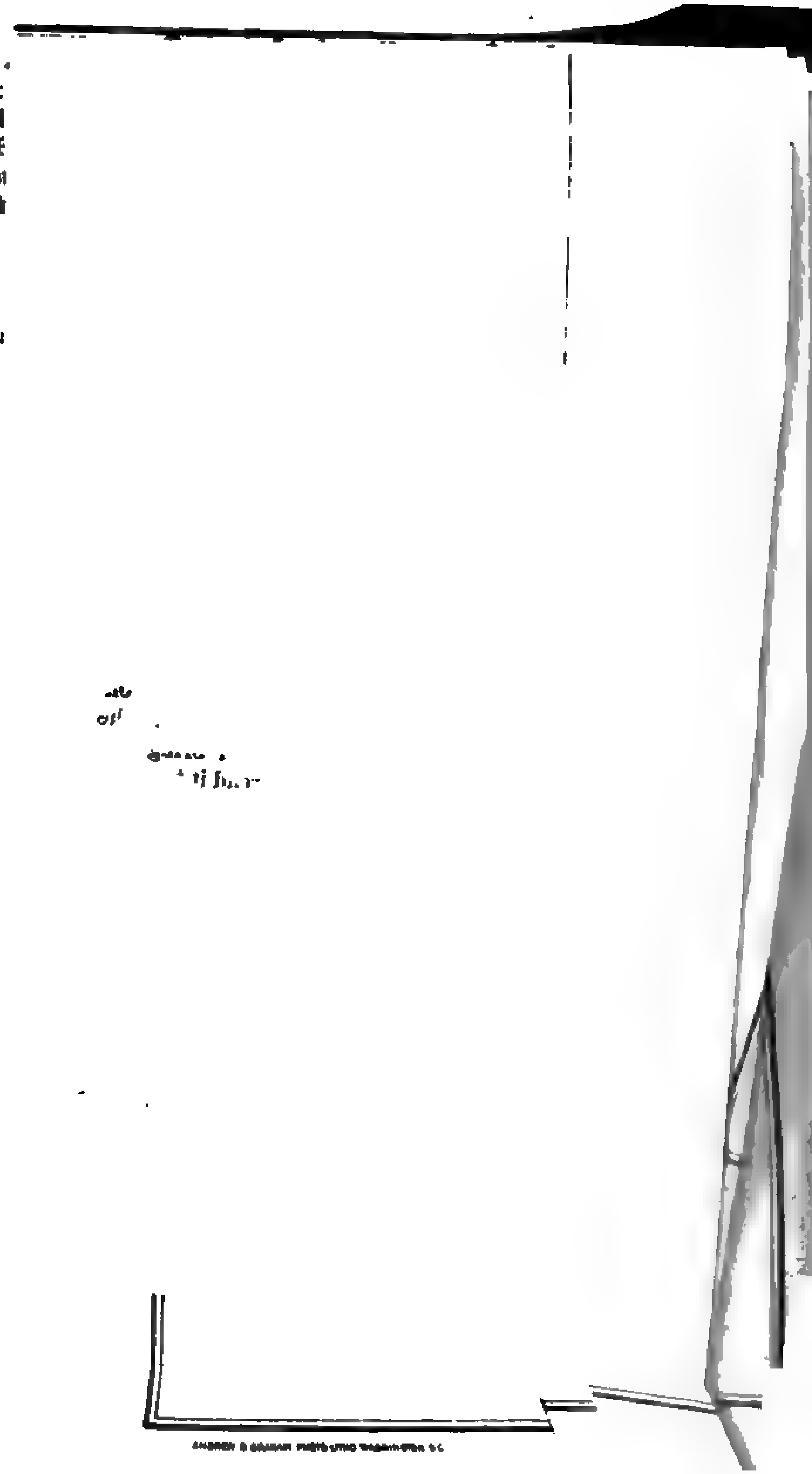


FIG. 4.—Diagram showing variation in the flow of streams and in the use of water in irrigation for the different months of the irrigation period and the relation between the available supply and the needs of agriculture. *A*, Discharge of the Laramie River at Woods, Wyo. Scale, 1 inch equals 30,000 acre feet. *B*, Use of water, from measurements at Wheatland, Wyo.

charge reached 3,400 cubic feet per second, while in 1898 it was not half that volume. In 1897 its run off would have covered 218,000 acres 1 foot deep, while in 1898 the run off was only 111,000 acre feet. In 1897 the maximum discharge of over 3,000 feet in May had fallen to



feet in June, and to less than 600 feet in July, while in 1898 the maximum flow of less than 1,600 feet in May had fallen to less than feet in July, and disappeared entirely in September. Great as are the fluctuations in discharge in the different months of the irrigation season, the variations in use are not less striking. On page 34 are two diagrams (fig. 4) to illustrate this. One (*A*) shows the relative discharges of the different months of the irrigation season; the other (*B*) the relative amounts used during these months. Both are taken from actual measurements. It will be seen that for every gallon of water used in May ten were used in June, while, on the other hand, three gallons were used in June for every one used in July. The shrinkage in use from June to July, while not so great as the falling off in discharge, was in the same direction, and by limiting a right to this actual use many more priorities could be satisfied than can be if the rights are fixed at a uniform continuous flow. These latter rights are either based on the capacity of the ditch or on the maximum requirements of the land, instead of on a mean of all the months in which irrigation is needed. Hence, a right for a continuous flow of the same amount, if based on the quantity used in June, gives its holder three times what he needs in July. Or if the stream is nearly appropriated when it shrinks from the June to July discharge, the holders of less than one-third of the rights own all the water.

STATE CONTROL OF STREAMS.

Plate II is a map of the Little Laramie River and the ditches which take water therefrom. It is a typical stream, and the map has been prepared to show the lack of system which prevails in the location of ditches and the accidental arrangement of the priorities along streams. The 130 different appropriations from this river are shown by the priority numbers placed after the names of the ditches. It will be noticed that priority No. 1 is below all others. Every other appropriator has a chance to divert the stream before its water reaches this ditch. So far as position goes there would be no possible chance to get anything in seasons of scanty supply because it often happens that one-half the head gates have to be closed. Even the second appropriator, 9 miles above, would not be much better off, because more than 100 diversions are made before the stream reaches his head gate. There are 50 ditches between his ditch and the thirtieth priority. The largest ditch on the stream irrigates more land than all the 15 first built, but its priority is 110. Realizing the danger of being so far down the list, its builders did all they could to offset this by a desirable position. Its head gate is far up in the hills on one of the branches of the main river, and it requires a journey of 40 miles from the head gate of number one to reach it.

More than 200 farmers depend on this stream for their living. To raise a crop they must have water when they need it, and as the stream

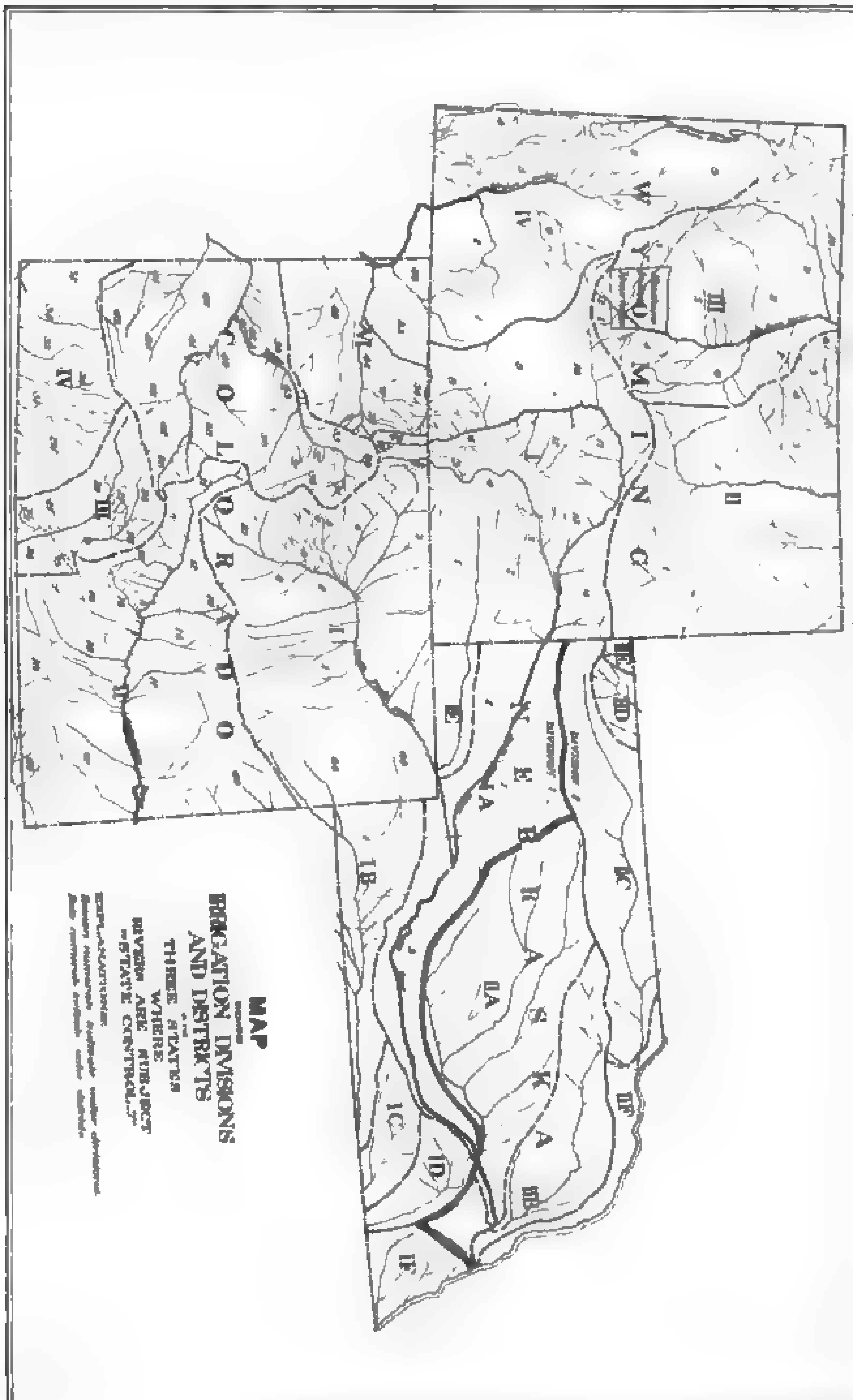
is fully appropriated they can secure this only by the most careful and economical use of the supply. Wasteful use above means parched fields and empty pockets below.

If there is not water enough for all, and this sometimes happens, some ditches have to be closed. The later ones have to be first shut down, and as fields watered by early and late priorities lie side by side, a late appropriator sometimes has to see his crops burn up, while on the other side of the fence those of his neighbor grows rank and luxuriant because of abundant moisture.

To control the division of a stream under these conditions requires administrative tact and ability of a high order. The appropriators can not attend to it themselves. The holder of the first right would have no time to use his right if he attempted to protect it himself. It takes a journey of nearly 200 miles to visit the head gates. In this and similar cases the individual is helpless; only State or community control will serve.

The division of streams is made much more complex by the variation in the discharge. The quantity to be distributed does not remain constant. It varies with every breeze that blows and with every passing cloud. It changes from day to day, from month to month, and from year to year. A daily record has never been kept of the flow of the Little Laramie, but one has been of the main stream. The variations in its discharge, as shown in Plate II, were equaled or exceeded by its tributary. An examination of that diagram and the one on page 34 shows that whenever appropriators exhaust a stream it requires something more than a court decree or order of a board to secure the largest service from the stream or protect the earlier rights. To do this there must be someone to stop waste on the part of the negligent and close the head gates of those who came late. No matter how rights are established, they amount to nothing unless protected. A decree or order fixing priorities is simply a guide to someone in closing head gates; unless there is some officer to execute it irrigators will not and can not respect it.

Thus far only three of the States drained by the Missouri seem to have realized this. Colorado, Wyoming, and Nebraska have been divided into drainage districts, and the streams used in irrigation are under the control of State officers. To Colorado belongs the credit of first recognizing the need of this public supervision, and the system devised has been followed in the other two States. Plate III shows the manner in which these States have been divided in order to make this control most efficient. The larger areas in each State are called divisions. The boundaries of these are drainage lines, and they comprise the basins of one or more rivers. The smaller areas are called districts, each district being formed of one or more tributaries of a stream or, in some cases in Colorado, of a section of the main river. The size of the district is governed by the number of ditches to be


MAP
IRRIGATION DIVISIONS
AND DISTRICTS
THREE STATES
WHERE
RIVERS ARE SUBJECT
STATE CONTROL
WYOMING
COLORADO
NEBRASKA

regulated and the importance of the interests to be served. In each State the head of the system is the State engineer; over each division is a superintendent, and in charge of each district is a water commissioner. The water commissioner is a police officer, whose duty is to execute the court decree in Colorado and the orders of the boards of control in Wyoming and Nebraska. He is given a list of the appropriations and the places where they are to be diverted, and as the stream rises and falls, he opens or closes the head gates of the ditches having later rights in such a way as to afford the earlier users the water they need so long as the stream supplies it. So far as the farmer is concerned the water commissioner is the most important officer with whom he comes in contact. On his action, and in many instances on his tact and judgment, depends the acreage of crops which come to maturity or the number of farms where the season's labor is lost. It will be seen that all of the preliminary steps in an irrigation code, the filing of the right and the determination of the priority, are simply preparatory to the work of the water commissioner. He is the enduring feature. Unless this code provides for State administration of streams, water rights can not be considered as having a stable and definite value.

The boundaries of the divisions in each of these States are fixed by law. In Colorado there are six divisions, in Wyoming four, and in Nebraska two. The boundaries of districts in Colorado are also established by the legislature; in Wyoming and Nebraska they are fixed by orders of the board of control. In Colorado the water districts are numbered from 1 to 69, the entire State being embraced in this consecutive numbering. In Wyoming the districts for each division are numbered separately, there being 14 districts in division No. 1, 7 in division No. 2, 10 in No. 3, and 9 in No. 4, or 40 in all. In Nebraska there is a double system of numbering, both divisions one and two being broken up into subdivisions marked by the letters of the alphabet.

The duties of the State engineer and of the superintendents are not the same in each State. In Colorado the division superintendent has general oversight of the work of commissioners in the districts of his division and controls the distribution of water between districts wherever a stream is divided up into sections, as are both the South Platte and Arkansas, in divisions one and two. The State engineer is at the head of the entire system. He furnishes both commissioners and superintendents with their instructions, and hears appeals from their action wherever parties feel aggrieved thereat. The duties of engineer, superintendents, and commissioners in Colorado are, however, only administrative. They take the districts as the legislature has defined them and the priorities as the courts have decreed them and divide the water in accordance therewith.

In Wyoming the State engineer and four division superintendents perform the same administrative duties as do these officers in Colo-

rado. But in addition they exercise a larger measure of authority and hold positions of greater responsibility. They constitute the State board of control, and are the custodians of the State's water supply. They determine what filings shall be approved, pass upon the proofs of appropriators, and issue the certificates of appropriation. Because rights to water are established by judicial decree in other States, it is the custom of those not familiar with the differences in the water laws to regard this board as exercising important judicial powers; but in fact they are seldom called upon to exercise such powers even in a limited degree, and then only in the determination of rights acquired under the Territorial law. The surveys of ditches and irrigated lands are made under the direction of the State engineer. The examinations of ditches and of lands irrigated are usually made by the division superintendent or his deputy. But the performance of these duties and the issuance of certificates based thereon are no more judicial acts than are the examinations of the irrigation of desert filings by a public land inspector or the taking of proof of reclamation by the register and receiver of the land office. The questions which have to be dealt with are, however, much more complex than those relating to land titles, and the board is an important body, charged with serious responsibilities. Special training, capacity, and experience are required of its members to insure its complete success. Thus far this has been recognized. It is one of the branches of the State government where the merit system has been adopted in the civil service. Three of the original members have served continuously since the admission of the Territory as a State. Several water commissioners have also served continuously. In this way a personal familiarity with the irrigation development of the State has been acquired, which is of the utmost value.

In Nebraska the State engineer has a dual responsibility. He exercises the same direction over the work of water commissioners as the engineers of Wyoming and Colorado. But in addition, as in Wyoming, his office is also the office of record of water-right filings for the entire State, and he is a member of the board which determines the rights acquired. The Nebraska and Wyoming boards of control are, however, differently constituted. In Nebraska its members are the governor, the attorney-general, and commissioner of public lands and buildings. The State engineer is secretary and executive officer.

WATER-RIGHT LAWS IN THE MISSOURI RIVER DRAINAGE BASIN.[1]

Those who read the following discussion of the State laws must keep in mind that they do not attempt to deal with the entire irrigation code of any State. On the contrary, only one subject—the methods of acquiring title to the public water supply—is considered. While there are other irrigation questions of great moment which have already been, or must soon be, made the subject of legislation, it would have tended to obscure the relation of stable water rights to the success of irrigation to have presented them here.

While the issues created by many of the laws to promote canal building are important, and many laws, like those accepting the Carey act or the bonding of the land of districts, are experiments, the fact remains that the most momentous issue in this as in all other irrigated lands is the framing of laws to protect the actual user of water in his reasonable and proper use.

WATER LAWS OF COLORADO.

By Hon. JOHN E. FIELDS, *State Engineer.*

Colorado, the pioneer in purely irrigation laws in the United States, has of necessity been compelled to develop its own regulations as the needs of the moment required, these leading often to unforeseen difficulties. Separated from Europe as we were in the early days, it was impossible for us to study the methods as developed through the ages. Doing the best according to our light as each emergency arose, we have developed a system at once a guide and a warning to those who have followed. The common law, as developed in England and fostered in the humid climate of our own country, was, under the altered conditions of the arid region, inapplicable; and water, instead of being a mere incident to the soil, rose when appropriated to the dignity of a distinct usufructuary estate or right of property. "The common-law doctrine as to riparian rights is inapplicable to Colorado." (Coffin *v.* Lefthand Ditch Company, 6 Colo., 447.)

Though California and Nevada preceded Colorado in the appropriation of water, they had the problem of water for placer mining, rather than for irrigation, as the matter of first importance, and so developed

[1] A second bulletin (No. 60) of this series gives extracts of water-right laws and forms of procedure in acquiring titles to water.

a system, which while probably well adapted to their own uses, is not adaptable to appropriations for strictly irrigation purposes.

The criticism of the Colorado system that it overrides the common law (the natural law and rights of the humid region), that it places parties remote from a stream upon the same footing as those settled along the banks, that the settler may be deprived of rights he has enjoyed for years, and that it permits unlimited invasion of private lands for the purpose of constructing ditches is, I think, unjust.

In the first place the early settler along the stream, not having diverted the water, had no use for it other than for domestic and stock purposes; or, if perchance his meadow was overflowed or benefited by the abundance of water in the stream, he still has the right whenever the diversion is so great as to injuriously affect him to construct a ditch sufficient to irrigate the meadow land. Unlimited invasion of rights is not permitted, the most feasible route and the least number of ditches only being allowed, and only upon payment of just compensation.

Our law results in the greatest good to the greatest number; encourages the reclamation of the best (the mesa) land; encourages economy of use; and as our laws and the custom of appropriation were prior to or coincident with the settlement along the streams, settlers had no vested rights, and settled with the full knowledge of the rights of others. The only possible injustice might be to the citizens of a neighboring State, and indeed this has caused some agitation of late, the merits of which question I will not here discuss, except to say that probably our appropriations antedate the settlement of their State, and that they had knowledge of the probabilities of a scarcity of water in the streams. Ultimately, however, I believe that seepage and return waters will result in a more uniform and desirable flow on the lower portions of the river.

The earliest irrigation in Colorado was practiced by the Mexicans along the streams in the southerly part of the territory, and taught us little of economical methods or the rights of water, and less of the great diversity of crops possible under irrigation. The ditches were generally small and in the immediate vicinity of the streams, covering only the low bottom lands, with small areas and insignificant crops.

When the bottom lands were exhausted for settlement the mesas were next taken up, and then, of necessity, began the construction of larger, longer, and more expensive canals, requiring the combined efforts of a number of settlers.

The most advanced of these efforts, known as community enterprises, resulted in the settlement of Greeley in 1870, whose example has since been generally followed in all parts of the State. Some eight years later began the era of canal building by corporations, using large amounts of outside capital and reclaiming many thousands of acres. The area of the irrigated land amounted in 1884, according to the estimate of the State engineer, to about 1,000,000 acres, and in 1897,

from the same source, to 2,000,000 acres, the great majority of which was reclaimed from the uplands and by corporate or community enterprises. I would say, however, that I consider the figures for 1884 excessive, while those of 1897 are probably much too low, as they represent simply the aggregate acreage, as reported by the water commissioners of the several districts, a number of whom filed no reports.

As between the rights acquired under the Territorial laws and those acquired since the adoption of the State constitution, there appears to be no difference. By the Territorial laws of 1861 the owners of land along a stream were entitled to water, and "the water of every natural stream not heretofore appropriated * * * is hereby declared the property of the public, and is dedicated to the people of the State subject to appropriation." (Article 5, constitution.) These, with the act of Congress of 1866 ratifying the right of appropriation, are the basis of the right of appropriation under State and Territorial laws.

No records of the early appropriations were required, and except in rare instances no filings whatever were made, and it was generally supposed at that time that a deed to land carried the right of water with it. This supposition was undoubtedly correct as to private ditches, constructed for the express purpose of irrigating a given piece of land, but does not apply to corporate ditches in which the water right is represented by stock in the corporation. It was not until 1881 that any provision was made for recording water rights. By this law claims were filed with the county clerk only. By the amendment of 1887 it was required that they be also filed with the State engineer. Not until 1879 was any provision made for the proper control and distribution of the waters by and under State authority. At that time water districts were created and commissioners appointed, but the law being defective in many respects, was repealed, and another passed by the legislature in 1881, at which time the offices of State engineer and superintendents of irrigation were created. As early as 1861, however, the legislature foresaw the necessity of providing for the distribution of water, and anticipated a shortage in the supply. This law of 1861, as amended in 1870, provided that the county judge should appoint three commissioners, whose duty it was "to apportion in a just and equitable proportion a certain amount of said water, upon certain or alternate weekly days, to different localities, as they may in their judgment think best for the interest of all parties concerned and with due regard to the legal rights of all."

It appears that, while this law was never repealed, that "due regard to the legal rights of all," in accordance with the court decisions, made it inoperative, inasmuch as the "legal rights" of an appropriator gave him a continuous flow to the amount of his decree, of which he could not be deprived on certain or alternate days for the benefit of a later decree. (Farmers, etc., *v.* Southworth, 13 Colo., 111.) And the only prorating allowable in this State is between the owner or users in com-

mon of a ditch or reservoir. (Laws of 1879, p. 97.) Here priority of use does not apply, as "consumers taking water from a carrier within a reasonable time after the carrier's diversion have the same priority dating from such diversion. As to such consumers, the prorating is constitutional." (Farmers, etc., *v.* Southworth, 13 Colo., 111.)

The courts were first given power in the establishment of decrees by the legislature in 1879, and jurisdiction was then vested exclusively in the district court. In 1881 a similar law was passed, providing that "every person * * * within any water district shall, on or before June 1, 1881, file with the clerk of the district court * * * a statement of claim, which shall contain the name and post-office address of claimants, name of canal or reservoir, and a description thereof, source of supply, date of appropriation by original construction, and also of enlargement."

While the filing of this claim was mandatory, in later decisions its omission was adjudged not a fatal defect in proving an appropriation and obtaining a decree.

The act of June 1, 1881, provides that anyone may petition the court for adjudication of water rights, and the court then will appoint a day for the hearing, and render a decision in accordance with the proof and evidence submitted. Proper notice to interested parties is provided for, the court having power to make just rules and regulations. The court, for good cause shown, may review the evidence within two years; and in case of appeal to the supreme court that court may amend or make a new decree or remand with instructions. But after a lapse of four years from the time of rendering a decree, all parties whose interests are thereby affected shall be deemed and held to have acquiesced in the same.[1] In all these proceedings ample provision is made protecting interested parties; but in no place is the State made a party. Waters are appropriated, decrees granted, and the right to use passed to individuals; and the State, the most interested party, and the interests of appropriators yet to come, are ignored.

In this State the first step in obtaining title to water is to file a statement of the appropriation in the offices of the State engineer and the county recorder. The date of appropriation may be the date of the commencement of the survey, and work must begin within ninety days from the date of the certificate, prosecuted with due diligence, and completed within two years. In the case of flumes, however, or of a company formed for the purpose of constructing a ditch, three years are allowed for the completion of the work. The water having been beneficially applied and the work completed, an adjudication of priorities is in order. There is first filed with the clerk of the district court a statement of claim setting forth the names of the applicants, name of the ditches, their location, dimensions, etc., and the court is then petitioned to set a time for the hearing of evidence. It is the

[1] The present attitude of the courts is that after two years a decree is unassailable.

custom generally for the court to appoint a referee, who hears and takes the evidence. Said referee sets a day for the hearing to begin, and, if the district is large, designates several dates when he will take evidence in as many different localities. Notice of hearing is given by publication in local papers and by posting in conspicuous places throughout the district for at least twenty days prior to the date set for hearing. With this notice is a copy of the order appointing him as such referee, and all interested parties, as appears by the application, are notified, and all other persons within the district are directed to file their application in similar manner. At the trial all interested parties may give evidence, and all evidence previously given is open for inspection. Failure to offer evidence deprives the delinquent of the right to use water in case of scarcity until such time as he shall have made application and obtained a decree in the regular manner. The referee having submitted his findings in writing to the court, there being no exceptions made, the court finds in accordance therewith; the priorities being numbered consecutively in the order of their dates, ditches and reservoirs being in a separate series. Copies of the decree are furnished to the superintendent of the division and are kept in the office of the State engineer.

Companies incorporated for the purpose may in like manner appropriate water and obtain decrees for the users under their canal, and may charge an annual rental for the carrying of the water. They are prohibited from exacting a royalty or requiring an advance payment of the annual charges. The maximum annual charges may be fixed by the board of county commissioners of the county in which the lands irrigated lie, and the common carrier, as such, must, when application is made by a consumer and proper tender made, sell him the amount of water necessary so long as there is a supply. (Wheeler *v.* Northern Colo. I. Co., 10 Colo., 582.) And any person who shall have purchased water for irrigation, and shall not have ceased to do so with the intent to procure water from some other source, shall have the right to continue to purchase water in the same amount on paying or tendering the price fixed.

A decree having been obtained, the right to the use of water continuously to the extent of the decree holds; and all or any part may be sold or transferred to other parties. (Knowles *v.* Clear Creek P. R. & M. D. Co., Supreme Court Colo., 32 Pac., 279.) The surplus waters from either an excessive decree or the result of a higher duty may be carried by extensions of the ditch to new lands and there applied (Coffin *v.* Lefthand Ditch Co., 6 Colo., 449); or it may be transferred either up or down the stream, provided other decrees are not injuriously affected. (Laws, 1881, p. 664.)

It may be transferred to a different drainage. (Coffin *v.* Lefthand Ditch Co., 6 Colo., 443; also Laws, 1897, p. 178, and Hammond *v.* Rose, 11 Colo., 526.) In fact there appears to be no limitation placed upon the

possessor except by the laws of nature and the established rights of others.

In case a ditch can not carry the amount of water decreed it, enlargement is permitted, unless parties injuriously affected bring suit and prove abandonment; but what constitutes abandonment is indefinite, for "it is not reasonable to suppose that the priority of right of water where water is scarce or likely to become so will be lightly sacrificed or surrendered by its owner." (Rominger *v.* Squires, 9 Colo., 329.)

A person on whose land water rises has the first right to the use of such water, but not as against the established rights of others lower down on the stream.

Seepage and waste waters may be appropriated, and are governed by the same laws as waters from running streams. (Laws, 1889, p. 215.) Persons who shall have enjoyed the use of water of a stream upon meadow lands by natural overflow are permitted, in case of the diminishing of the flow to the extent of depriving them of the benefits of such overflow, to construct a ditch to irrigate such meadow, the date of priority being the same as though the ditch had been constructed at the time such meadow was first occupied as meadow ground. (Laws, 1879, p. 106.)

Right of way for ditches may be obtained, limited to the shortest and most feasible route, and the number of ditches, whether owned by one or more parties kept at the minimum, and to this end existing ditches may be enlarged to accommodate the waters of the later comers. (Laws, 1881, p. 164.) Ditches are not subject to taxes, except where the same are constructed for the purpose of deriving a revenue therefrom. (Laws, 1872, p. 143.)

By the laws of 1879 (p. 106), persons desiring to construct and maintain reservoirs for the purpose of storing water may take any unappropriated waters for that purpose, or those not needed immediately for domestic or irrigating purposes, and may conduct such waters therefrom in the bed of any natural stream, and divert the same again without regard to priorities of others, allowance having been made for loss in transit; and, for the more accurate measurement of the waters when so conducted, must maintain an automatic or self-registering device in a measuring flume or weir at the outlet of the reservoir.

Domestic is a higher and preferred use to irrigation or manufacturing, but only in so far as to have the right of condemnation. It is not permitted to wastefully conduct water for domestic purposes in large open canals. The abandonment of the use of water by a mill does not cause the water to revert to the public for use in the order of priority of all the ditches on the stream, but it continues to supply those ditches in order of priority which enjoyed the benefit of the returns of such water to the stream after having performed its duty for the mill.

Aside from making the proper filings and obtaining decrees, owners of canals and ditches must maintain embankments, proper waste ways

at the nearest practical point to the head gate, bridges and crossings; and, when in the limits of a city of the first-class, canals and ditches must be covered and provided with sufficient safeguards to the public. Owners must prevent waste, are not allowed to use an excess of water, and must keep head gates and measuring flumes in repair. All owners of canals carrying water for pay shall, when demanded, keep water in their canals from April 1 to November 1, so far as practicable.

It is the duty of a consumer to see that he obtains no more water than rightfully belongs to him. (Laws, 1887, p. 312.) Co-owners must pay their pro rata of expenses; such expenditures may become a lien on the interest of any delinquent.

The State is divided first into six grand divisions, over each of which is an officer called a superintendent, each division representing a certain drainage area. No. 1 is the South Platte drainage; No. 2, the Arkansas; No. 3, the Rio Grande, etc. Each of these divisions is divided again into numerous districts, each under the direction of a water commissioner, of which there are 69 in the State; generally speaking, they include the drainage of a certain tributary or portion of the main stream. The commisioners may appoint deputies to assist them. (See map, Plate III.)

The administrative department consists of the State engineer and the six superintendents of divisions appointed by the governor, and of the water commissioners, also appointed by the governor from nominations made by the board of county commissioners. The State engineer is paid from State funds, while the superintendents and commissioners are paid by the counties into which their jurisdiction extends.

The duties of the State engineer are numerous. Besides having charge of State engineering work and acting as adviser in that capacity for the different departments, he is the head of the irrigation officers, to whom appeal may be made from commissioners and superintendents. He has supervising control over the public waters, makes measurements of the flow of the streams, collects data on irrigation works, canals, reservoirs, and artesian wells as well as on the snow fall, and estimates the probable supply of water from that source. Designs and plans for dams in excess of 10 feet in height are subject to his approval. He furnishes the commissioners and superintendents data and information for the proper and intelligent discharge of their duties; requires the owners to supply ditches with measuring devices, and superintends their construction, rates the flumes, and in addition collects statistics of crops and the water used in the different ditches by districts.

The superintendent of a division has general control over the water commissioners in his division, and has the power to call out commissioners at any time. He is furnished by the clerk of the district court with copies of decrees, tabulates the same, and furnishes the commissioners with a copy thereof for the ditches in each district; but his especial and main duty is to regulate the flow of water into and from

each district, so that priorities of equal date receive water, or are shut off in the different districts throughout his entire division.

The commissioners report to him each week the names of ditches drawing water, and if the supply runs short make a request for water, and when it occurs that ditches of a later decree in the district next above are receiving water, the superintendent orders such ditches closed and the water sent down to the older appropriators below. The commissioner has direct charge of the head gates. It is his duty to open or close the same in accordance with date of priority and to see that water goes into the next district below in compliance with instructions from the superintendent. It is his duty to see that water is not wasted; he is invested with police authority and may arrest any person violating his orders. He must devote his entire time to his official duties; report head gates and rating flumes not kept in repair; and each season prepare a tabulated statement for his district giving the name of ditch, average amount of water carried for the season, number of days water was carried, number of acres in alfalfa, wild hay, grain, and fruit, also number of acres capable of being irrigated from each ditch.

In their fundamental principles the Colorado irrigation laws are good—i. e., that the water is the property of the people and its use subject to priority of appropriation dependent on its beneficial use. But the principle of next importance is, I think, in error—that is, the segregation of the water from the land—and the right of transfer gives too great privileges to the appropriator and tends in practice to the possession of the water itself, and not simply to the right to its use.

An appropriator primarily takes water for a specific purpose for a definite tract of land, and is granted as much as is necessary for his use, with a fixed maximum also conditioned on its beneficial and economic use. Thus in the very beginning unused or surplus water does not belong to him; and why, then, should he be permitted to sell and transfer what is not his? Where would be the hardship in permitting him to continue the use of water as he had always used it? Obviously, there would be none, and there is no chance for abuses if the law prohibiting waste is enforced, as the only possible abuse would be wasteful application. But with the transfer of the water to other land and other owners infinite complications arise. The first question is, whether any one is injuriously affected by the change; under the new conditions will the same water be diverted? Would not the priority be supplied by seepage or tributaries between the two points? Is the change depriving someone below of his seepage and waste? Is not the entire burden of loss thrown on the users below? These are things that the efficient administration of the law can not prevent. In addition, there are the abuses incident to our imperfect method of appropriation and decrees. Many decrees, and especially our early ones, were greatly in excess of the amount actually put to a beneficial use. Permitting the use of a certain appropriation on other lands encourages the gradual enlarge-

ment of ditches to their full decree to the detriment of all subsequent decrees. While this may be small in a particular case (which it often is not), yet in the aggregate the loss to later decrees is disastrous. With the offenses scattered in time and place, the damages indefinite and small at any particular time, but insidious and persistent, though slow, in their encroachments, the injured parties, also numerous and scattered, with a common cause, but not united, the offense goes unrectified until by their own inaction the injured appear to acquiesce in their own destruction.

This enlargement of ditches, I believe, is not in accordance with court decisions, yet there is one case I can not refrain from quoting, which is so obvious in its tendencies as to require no comments. I quote verbatim from pages 52 and 53 of the fifth biennial report of the State engineer for 1889 and 1890:

DAVID A. RANKIN et al., plaintiffs,
v.
THE COLORADO AGRICULTURAL DITCH COMPANY, THE CLEAR CREEK AND PLATTE RIVER MILL AND DITCH COMPANY, et al., defendants.

The groundwork for the complaint was an application on the part of the plaintiffs to this department to have the water decreed to the Clear Creek and Platte River Mill and Ditch Company, by virtue of its enlargement in 1863, to wit, 20.56 cubic feet of water per second of time, turned into the Colorado Agricultural Ditch, alleging that the two ditches had the same head gate; that their lines were practically parallel and contiguous; and that this water was originally appropriated to and for their lands, which lay, principally, under the Clear Creek and Platte River Ditch; but on account of the difficulty of diverting the water at the head of the latter ditch, and for the purpose of securing a full and uniform flow of water, they had constructed the Colorado Agricultural Ditch.

For the purpose of determining the matter of the application, I had an examination and measurement made of the Clear Creek and Platte River Ditch, from which it was ascertained that the points of diversion of the two ditches were originally about 80 rods apart, that of the Colorado Agricultural Ditch being the upper; that owing to the difficulty of maintaining a head gate and dam at the lower place the two were merged into one and the waters of both ditches carried in the Colorado Agricultural Ditch to a point of divergence near the old head of the Clear Creek and Platte River Ditch, and further that the Clear Creek and Platte River Ditch did not have at the time of measurement and, from the best information obtainable, never had capacity sufficient to carry the water decreed under its original appropriation; and that consequently any waters used on the lands of the plaintiffs from the latter ditch must have been from that original appropriation; that they could not have appropriated and used water the ditch could not carry.

Had the application been made to transfer a portion of the water decreed under the original construction (within the limits of the ditch's capacity) a different conclusion would probably have been arrived at, for it was not intended to deny the right of the plaintiffs to carry the water justly belonging to them through the best and most economical channels onto their lands.

The Colorado Agricultural has a decree for 30.20 cubic feet, dated March 5, 1867.

The Clear Creek and Platte River has a decree for 49.50 cubic feet, under original construction, dated November 1, 1861, and for 20.56 cubic feet, under enlargement, dated November 5, 1863.

The effect of such a permit would be to give the Colorado Agricultural, a ditch constructed in 1867, a decree for 20.56 cubic feet, dating back to 1863, and this water must be taken from some other ditch having an appropriation prior to the latter date, because it could not be taken from the Clear Creek and Platte River, a ditch that could not carry it and had, therefore, never appropriated it.

The court ordered and adjudged that the officers of this department be directed to turn and allow to flow in the Colorado Agricultural Ditch all of the water appropriated and decreed to the said Clear Creek and Platte River Mill and Ditch Company, by virtue of its enlargement in 1863, to wit, 20.56 cubic feet of water per second of time.

As to remedies for this evil there is one, I think, that would meet the requirements and put a stop to future enlargements. Each ditch should have its maximum capacity determined and made a matter of record, and this amount should remain the maximum amount allowed the ditch, notwithstanding any decree in excess thereof; and in case of more than one decree for a ditch, the most liberal interpretation should be given by allowing the quantity to be distributed to each decree in order of priority until exhausted, thus annulling the latest decrees first, the second latest next, and so on.

To prevent a continuance of the abuses I believe that applicants for a decree should be compelled to show a certificate from the State engineer that he has examined their ditch, and that its capacity, length, course, number of acres under it, kind of soil, and probable amount of water required have been determined by him, giving in the certificate these various items.

This would be of great value to the judge or referee; would be both expert and practical testimony by a disinterested witness; the State would be very properly represented; the interests of subsequent appropriators would be protected, and at the same time a valuable record of the canals and irrigation works of the State would be secured.

In the case of large enterprises, where considerable time for both construction and settlement is necessary, there could be a declaration of intention and a time fixed by the State engineer for the completion of the work. If completed within the specified time, then priority to date from the commencement of work; if not, priority granted bearing that date, but for an amount proportionate to the work completed. Should the company care to continue the work, allow another declaration of intention, as in the first instance.

I have here given only a few of the evils which beset us of Colorado, and have not attempted to discuss at length the merits or demerits of the systems of attaching and separating the land and the water. This has been ably done by others and at greater length than permitted me here;[1] both experience and history point one way.

He who expects the letter of the law in relation to irrigation to be executed with the precision of clockwork, and that infallible results will be obtained, has a small conception of the tangled web of diffi-

[1] See State engineer's report, Wyoming, 1895 and 1896, p. 57.

culties in the way, and a meager knowledge of the uncertainties of the element manipulated.

Therefore, I claim that the administration of water, except on the broadest principles, should not be reduced to a law. It is impossible to fix a rule that will meet any but exceptional cases, and the only practical way to properly administer the laws we have is to give the greatest possible latitude to the irrigation department, subject always to review by the courts. My experience is that it is rare to find an officer who has not the good of his district at heart, and there are fewer charges of favoritism or injustice than there are that the letter of the law has not been followed and the pound of flesh allowed. What few complaints have come to me have resulted from mere differences in the interpretation of the law.

The officers should be selected with a view to their fitness for the places they have to fill, and should not be subject to local influences. Dependent as our commissioners are for both their positions and pay on the whim of the county officials, the results can not be entirely satisfactory. Therefore both superintendent and commissioners should be appointed by the governor and paid by the State. Aspirants for appointment should be qualified to perform their duties intelligently, and be able to compute the flow of water.

The commissioners should be empowered, in case of refusal of the owners of any ditch to place head gates, make repairs, or to obey orders, to shut the water off until such orders are complied with, and when water has been turned off and the consumer notified thereof, anyone using water which may be in the ditch, contrary to orders, should be deemed guilty the same as if he had opened the head gate. Officers of the irrigation department should be defended in all actions by the district attorney, and costs should in no case be adjudged against them except in case of willful oppression or malfeasance, and parties beneficially interested should be made parties to the suit.

I regret that it is not permitted in this State to rotate water, as by that method a much higher efficiency could be obtained. When each user is allowed all the water he can handle for, say, two days each week, he prepares himself, and when the water comes every drop counts. More land is irrigated in less time; there is no water running to waste and washing out gullies at night; seepage and evaporation are lessened in the laterals, and when the two days are up he can do something else, and is not harassed to death with an intermittent little stream, the results of "borrowing" on the sly by his neighbors.

The State engineer should be vested with power, in case of emergencies, to arbitrarily divert water for strictly domestic use, as it often happens that settlers under a ditch which has been closed suffer greatly for water for themselves and for their stock.

As between seepage and waste waters and the natural flow from existing springs, it appears to me the line is not sufficiently marked.

If the former has for a number of years been finding its way to the streams, and appropriators, albeit unconsciously, have been using this water, an appropriator of this water before it reaches the river should be allowed to use only the amount of the increase which is the result of his labor in reclaiming the water.

WATER LAWS OF KANSAS.

In the western third of Kansas irrigation is a necessity, but this fact was not realized until the greater part of that region had been settled and the failure of agriculture by rainfall established by experience. This explains some of the features of the Kansas irrigation laws which are peculiar to that State.

The act of 1897 is not general, but only applies to that portion of the State west of the ninety-ninth meridian. The earlier acts applied to the entire State. While this creates no conflicts, it does give rise to some complexities. The doctrine of riparian rights seems to prevail in the eastern two-thirds of the State, while the right to appropriate streams west of the ninety-ninth meridian is specifically conferred by the act of 1897. As all of the important streams of the State flow from west to east, one doctrine prevails at their sources and an antagonistic one at their outlets.

The laws of Kansas resemble those of North Dakota in the prominence given to underground waters. In Dakota this comes from the unusual importance of this supply; in Kansas, from the unusual need of it. When western Kansas was settled, no particular attention was given to securing locations which could be irrigated. The uplands were settled as rapidly as the valleys. The number of homesteaders remote from streams is far greater than the number which can be supplied therefrom. It is only by the utilization of underground or stored water that many of the upland farms can be watered. Hence, legislation has been directed toward the determination of its volume and the enactment of laws to promote its use.

So far as the declaratory provisions of the Kansas water laws are concerned, there is little to criticise. They are generally in accord with the best thought and experience of the West, but when we come to consider the means provided for their administration the result is not so satisfactory. The principles laid down in chapter 79 of the compiled laws of 1897, relative to the appropriation of water, are conservative and just. The right to appropriate both surface and underground waters is recognized, but such right is restricted to the beneficial use of the volume appropriated, and a failure to continue such beneficial use forfeits the right. No appropriation is complete until the water has been used, and the amount of the appropriation is limited to the requirements of that use. Any person attempting to sell, lease, or assign a right of this kind is held to have abandoned it, and there is a stringent penalty against the collection of royalties for the right to use water.

Under these laws the irrigators of Kansas are freed from many of the dangers of speculative ownership which threaten some of the States where the right to water is of far greater moment. In considering the merits of any irrigation code this fact must, however, be kept constantly in mind: Its effectiveness depends in a large measure upon the means provided for its enforcement. No declarations of principles will operate a railroad. In order that trains may run on time and passengers be transported in safety there must be superintendents and engineers and train dispatchers to direct the work. There is an equal necessity for some sort of administrative machinery to protect rights in the division of a running stream. It is here that the law of Kansas is defective. Authority is too widely distributed and no one has sufficient control to make it of much service. "Too many cooks spoil the broth," and too many branches of the State and county governments have a share in stream control to permit of satisfactory results. The county clerk posts notices of appropriation; that ends his connection with irrigation. The register of deeds records these notices and does no more. The district court adjudicates rights, and hears and determines petitions for the annulment of agreements to rotate water. The county records are of little value before it acts, while after such action they are of no consequence because the court decree displaces them as an evidence of title. Even this decree does no good without some way to enforce it. There appears to be none except to enjoin those who disregard its terms. Such a remedy is altogether too slow, expensive, and imperfect to be applied.

The rates for the carriage of water are fixed by the county commissioners, and this ends their connection with irrigation.

There are other controversies that have to be decided by the railroad commissioners. It would be a very unusual coincidence if men could be found fitted by experience to act as railroad commissioners who have the necessary experience to qualify them to act as irrigation experts. The only State official who is supposed to be specially fitted to deal with irrigation matters is ignored. There is a commissioner of irrigation and forestry, but his duties in supervising the acquirement of rights to water or the protection of those rights are not obvious from a study of the statutes. It is believed that this system is capable of betterment, and in support of this belief the following suggestions are offered:

Section 2 of chapter 79 says that the right to have an appropriation date from the filing of a notice depends upon the completion of the ditch within a reasonable time. What is a reasonable time? This has to be determined at some stage in the acquirement of the right. It ought to be fixed before construction begins. In that way injustice both to the parties building ditches or other parties whose rights are affected by such ditches can be most surely averted. By fixing the time allowed for completion before work begins, one of the prolific

sources of litigation is entirely removed. This has to vary with each ditch, and can not be attended to without some administrative head to the irrigation system of the State.

Section 4 of chapter 78 states that work must be begun within sixty days after posting the notice. How is compliance with this provision to be established? Ditches are often built in remote localities. There is nothing in the law which requires a report either of the beginning of construction or of the progress made, and there is no officer whose duty it is to look after these things to see that the law is complied with.

What has been said elsewhere regarding the necessity of some central office for all claims to water applies with peculiar force to Kansas. County boundaries have no relation to the drainage areas of streams or of the basins of the artesian-well supply. Where a river crosses many counties a notice filed in one county is not a sufficient notice to water users in other counties above or below. This has been recognized in the act which requires those who wish to establish a priority of right for an artesian well to file not only in the county where the well is situated, but in the adjoining counties also. If this is regarded as necessary to protect a priority for an artesian well, why should not a similar notice be filed in the other counties through which a stream flows? There the interference with rights is obvious; in the case of the artesian well it is largely a matter of conjecture. A central office of record would, however, be far superior to requiring separate notices in each county, and in the case of artesian-well filings would be immeasurably superior to the separate records of these notices in a few counties.

The establishment of any right on a stream influences the value of every other right. This is so obvious as not to need discussion, and of so much importance that it should be recognized. Apparently it has not been in the law governing adjudications. Priorities on a river ought to be established for the whole stream. Instead, they are in sections. The judge of one district fixes the priorities for his district; the judge of the district above or below establishes the rights in his, and the two have no relation to each other and afford no basis for a protection of all rights.

The law which requires reports from those sinking or boring artesian wells is excellent, and these statistics are destined to be of great service in the future. Their value is largely lost at present by their separation in the different county records and by the fact that they go to someone who is making no special study of these questions. It is believed that the benefits to the State would be much greater if those reports, instead of being pigeonholed in a county office, were sent to some experienced officer at the State capital. In that way the whole State could come under review and water users be promptly informed of any new discoveries of importance.

WATER LAWS OF MONTANA.

Measured by its agricultural possibilities, Montana is one of the foremost States of the arid region. Every important tributary of the Missouri used in irrigation, except the Platte, rises in or crosses this State. The volume of the available water supply and the area of land which can be reclaimed makes it certain that in time the irrigated farms will alone support more people and produce more wealth than all the industries of the State now do.

As yet this greatness is largely prospective. More water runs to waste in this State than is used in irrigation in all the States embraced in this discussion. Stock raising and mining are the two industries which absorb investments of capital and lead in public thought. Water-right questions have received comparatively little attention. It is the extent of the State's resources which has caused this neglect of legislation. So long as streams have a surplus and every user is supplied there is no need of laws. This has been the situation in Montana, and the need of framing a code to meet future requirements has not been recognized.

The water-right laws of this State are the outgrowth of the customs of the placer miner. Rivers were turned on gravel beds before they were on hay meadows, and the laws are largely copied from those of California, where the miner preceded the irrigator and where irrigation is not a general necessity. While the use of water in mining has not kept pace with the extension of irrigation, the influence of early customs still remains paramount.

In framing water laws there is especial need of a clear understanding of what is to be accomplished, and in providing for the use of water for mills, mines, or farms, the differences in these pursuits should be kept in mind. It has apparently been assumed that one water law would serve every purpose equally well. That mistake is not made in disposing of public land. We have one law for placers, another for homesteads. Titles to mineral veins are not secured through desert filings. These different laws are framed to conform to different conditions. There is an equal difference between the conditions which should govern rights to streams. In mining, the use is regular and continuous; in irrigation, it is intermittent and varies from month to month. In mining, the washing down of a placer bed ends the use of water at that place; in irrigation, the farm will be watered as long as the river runs. One is transient; the other permanent. In mining, but little of the volume diverted is absorbed or destroyed; the same supply can be appropriated and used over and over again. In irrigation, the greater part of the volume diverted is absorbed and lost.

Sales of water in mining are in reality simply charges for transportation and delivery, because the water returns to other users. A law making mining rights in streams personal property, while not regarded as necessary, does not inevitably lead to abuses, because the end of the

use is only a matter of time, and the return of the water to the stream gives a practically unrestricted field for others to acquire the same kind of right.

In irrigation making such rights personal property places users at the mercy of their holders, because it enables them to say who shall or shall not absorb the supply.

The changes made in the laws for acquiring water rights have been unimportant. The methods of filing claims, of measuring water, and of determining rights in the courts have been made more definite, but neither the nature of the rights acquired nor the methods of appropriation have been materially modified.

The first Territorial water laws recognized the right of appropriation and set aside, by implication at least, the doctrine of riparian rights. The right to appropriate water for the purpose of lease and sale is recognized, and the court decisions interpreting this statute seem to make water a form of personal property.

The only water-right provision in the constitution is a part of paragraph 15, article 3, of the Codes and Statutes of Montana for 1895. It reads as follows:

> The use of all water now appropriated, or that may hereafter be appropriated, for sale, rental, distribution, or other beneficial use, and the right of way over the lands of others for all ditches, dams, flumes, canals, and aqueducts necessarily used in connection therewith, shall be held to be a public use.

The right to appropriate water for the purpose of sale and rental is not conferred by the laws of the distinctly agricultural States embraced in this discussion, as will be seen by referring to the statutes of Kansas, Nebraska, and Wyoming. There is considerable uncertainty as to just what this involves. Many holders of appropriations believe it is an ownership in the river itself which authorizes an appropriator to sell or lease its waters to users regardless of any ditch or place of use, and parties claiming such rights have given warranty deeds to a definite volume of water from a river, to be diverted in ditches yet to be built. If this conception is correct, then the filing and establishment of titles in this State are of unusual importance to its future development.

Where the only right which can be acquired is that of use, and is to be measured in the future by that use, there is little danger to be feared from extravagant or speculative rights, because the holder can derive no benefit therefrom; but where parties acquire a right to a part or all of a stream, not for the purpose of making a beneficial use thereof, but for the purpose of selling it to those who in time must have it, the temptation to acquire as large an interest as possible and the difficulties in the way of preventing unreasonable appropriations are enormously increased.

Where rights to water are restricted to the land on which acquired the land is always a measure of the extent of the right, but where the location of use is not fixed and where the appropriation is to secure

water to sell, its limitation is fixed only by whatever the court may decree or by the size of the stream. It is not certain that the Montana law permits the acquirement of such rights, but it is true that many appropriators believe it does, and both the law and the declaration made encourage such belief. The notice of water right, in general use, is posted before the ditch is built, yet it states that the party doing this "has a legal right to the use, possession, and control" of the inches specified. It does not say he will have, or that he desires to have, but that he already has such possession.

Many Montana rivers are long. They wind their lonesome courses across the arid plain for hundreds of miles. The claims for ditches already built, and those to be built, are not being recorded for districts based on drainage lines, but by county boundaries which have no relation to such drainage. Sometimes these rivers form parts of county boundaries. Where this happens, the scattering of irrigation records is still more pronounced. Take the Musselshell River, for example. It forms a part of the boundary between Fergus and Meagher, Yellowstone, Dawson, and Custer counties. Ditches on one side of the stream are recorded in one county; ditches on the other side in another county. It would require a journey of hundreds of miles and the examination of five sets of records to learn of the claims to its waters, so that the obstacles to irrigators informing themselves are so great that the records are of little practical utility. Very few appropriators know anything of the claims of others or have any idea of their extent.

Furthermore, the connection of the county clerk with irrigation ends with his recording these statements. He has no further supervision. The law says that work on the ditch must begin within forty days, but it is made no one's duty to see that it does begin or to make a record of failure to begin. Nor is there any official measurement of these ditches, after they are constructed, to determine their capacity, nor any survey of their location to definitely fix the extent of the beneficial use of water, which their construction makes possible.

In investigating the accuracy of the water-right records of this State an examination was made of all the claims to a small stream lying wholly within one county. It showed that it was almost as easy to build a ditch as it was to ascertain its right to water. In this instance there were nine books containing records of claims. Many of these claims reached back to the early Territorial period, yet nothing had ever been done except to record them. As there is no provision in the law for "proving up," there was nothing to show whether the ditches had or had not been built, or the extent to which water had been used. In the earlier records they were scattered among land locations and mining locations. Sometimes a farm, a mine, and a river, would all be located and claimed in one document. Some of these claims were 30 years old, yet there never had been a survey or an adjudication to determine what the just rights of any of the claimants were.

It needs no argument to show that a record of this kind is of little value; that it not only does not protect the rights of those who actually build ditches, but, on the contrary, threatens to become a source of annoyance and expense to users in protecting those rights. To show why this is so, the claims to the water of Trout Creek, a small stream of Lewis and Clarke County, which has a mean discharge in the irrigation season of about 500 acre-inches, have been copied and are given below:

Rights to water from Trout Creek.

Book.	Page.	Amount.
1	2	2,000 inches.
1	7	400 inches.
1	10	1,000 inches.
1	13	3,000 inches.
1	18	2,000 inches.
1	19	1,000 inches.
1	22	All the water from a spring that empties into Trout Creek.
1	25	All the surplus water of Trout Creek.
1	28	Exclusive right to all the water in Trout Creek.
1	28	Claim all the water of the upper part of Trout Creek.
1	29	2,000 inches.
1	39	All the water in creek below ditch taking water to St. Louis bar.
1	42	500 inches.
1	43	All the water that can be "flown" in a ditch at any season of the year.
1	58	1,000 inches and all surplus water.
1	59	All the surplus water of Trout Creek.
1	68	All the water not then in use.
1	88	600 inches.
1	90	2,000 inches.
1	108	1,500 inches.
1	129	1,000 inches.
1	131	500 inches.
1	139	Do.
1	140	Do.
1	273	Do.
1	386	Do.
1	396	800 inches.
1	431	400 inches.
1	450	600 inches.
1	456	800 inches.
1	505	750 inches.

Many of these claims were recorded by homesteaders who had filed on 160 acres of land. It requires about 100 inches to irrigate that area, and anything above that would, so far as the homesteader was concerned, be a surplus. Furthermore, any claims to an excess of 500 inches, the mean discharge of the stream, would be of little value in themselves if the claims to that amount were actually used. Looking at the actual situation, therefore, if the first claim was a legitimate one it absorbed the stream four times over, and all the others are simply paper titles, injuring the first but having no value in themselves. Such is not the actual situation. Claimants have used what they actually needed without any regard to the recorded statements.

The record given above does not include all of the claims to the stream, but as it did include thirty or forty times the entire supply, it did not seem necessary to pursue the inquiry any further.

The records of claims on scores of other streams were looked over with similar results. They lead to one of two conclusions: To recognize as vested a right to all that is claimed will establish appropriations

for much more water than has been used, and will sooner or later compel all subsequent users to buy their supply from those whose rights have no better foundation than the ignorance or greed with which they filled out their notice of claim.

There is another clause in the Montana law which makes the situation more uncertain and the danger from these speculative filings more serious. Section 1897 contains the following:

> Every person having the right to use, sell, or dispose of water and to engage in using, selling, or disposing of the same, *who has a surplus not used or sold, or any person having a surplus of water and a right to sell and dispose of the same,* is required, upon the payment or tender to the person entitled thereto an amount equal to the usual and customary rates per inch, to convey and deliver to the person *such surplus of unsold water.*

This seems to indicate that a person can acquire an ownership in a stream of a surplus simply for the purpose of selling it. It is submitted to the actual users of water that it is a matter for grave consideration whether such rights are equitable or necessary, and whether there is any reason which will justify their establishment. The irrigated regions of the Old World have been prosperous just in proportion as they have restricted rights in rivers to that of use, while in those countries where water has been made personal property, and the man who owns the stream can levy toll on the man who tills the soil, there have been exactions without end and poverty and oppression for the irrigator.

Another obstacle to a definite understanding of the rights to Montana streams is the absence of any law providing for either their prompt or comprehensive determination. While the district court has authority to adjudicate these rights, when controversies arise between irrigators, and numerous adjudications have been had, there is great uncertainty as to whether all rights have been included, and much difficulty in finding the cases in which these rights have been an issue. There is no stream record of water-right cases, and as these decrees are rendered in private suits, which are only indexed in the names of the litigants, it is sometimes necessary to examine the entire trial record of the district court to learn what has been settled by judicial determination. An effort to trace down the water-right litigation on a few streams showed that court clerks, attorneys, and irrigators are often as much in the dark regarding the actual situation as an outsider, and the conclusion is unavoidable that a perpetuation of this system, or lack of it, for another quarter of a century would result in a chaos which would be almost beyond the ingenuity of man to unravel.

Another possible complication is the establishment of two or more sets of appropriations for the same stream. This is due to the fact that the boundaries of judicial districts are not based on drainage lines. One section of a stream may be in one district, another section in another. Litigation in one court will establish one set of priorities;

similar litigation in the other court will establish another; yet both are based on the same water supply, and no systematic administration is possible until both are brought into harmony.

The unit of measurement in Montana is the "inch" (sec. 1893), and the form of device to be employed in its measurement is fully set out in the statute. This again shows the influence of mining customs, as the States in which irrigation preceded mining have adopted the cubic foot per second as the standard of measurement. The latter is a definite unit, but the value of the inch depends entirely upon securing uniform conditions. This may be possible in distributing water from ditches, but it can not be employed in measuring a river or in dividing its flow among canals. To use the device described in the Montana statute to measure the volume turned into some canals would require a box a thousand feet long and a locomotive to pull the slide. In a few States both methods of measurement are recognized by law, and there seems no reason why such would not be an excellent arrangement in Montana. This would enable those who are accustomed to the "inch," or where contracts have been based thereon, to continue its use, and would legalize the employment of the cubic foot per second in the gauging of rivers and canals.

The great rivers and fertile plains of this State are resources of such importance as to warrant the framing of an efficient code of laws for their utilization. It is believed that the experience of the Commonwealths on both the north and south are worthy of study, and that the following changes in the present code would promote development and add to the value of irrigated land:

All records of claims or titles to water from a stream should be recorded in one office.

There should be some authority to supervise the filing of claims and to prevent the overappropriation of streams.

Completed ditches should be measured by the State and rights established by some less costly method than litigation.

The State should be divided into districts and officers appointed to protect prior rights in times of scarcity.

WATER LAWS OF NEBRASKA.

By Hon. J. M. Wilson, *State Engineer.*

Water rights in Nebraska may be briefly divided into the following general classes:

(1) Rights acquired by actual use prior to the passage of the first general irrigation law, March 4, 1889.

(2) Rights acquired by compliance with the law in force from March 4, 1889, to April 4, 1895.

(3) Rights acquired under the law in force from April 4, 1895, up to the present time.

(4) Rights acquired since the enactment of the irrigation law in 1889 by those who, without complying with all of the provisions of the law, actually constructed works and made beneficial use of the water.

To the first class belong many valuable mill claims and several of the earlier irrigation rights. Of many of these claims there was up to 1889 no public recognition. Only those who had been so unfortunate as to get into court could boast of a record. The settler, driven by his repeated failures in dry farming to seek relief in irrigation, had no means of determining what rights were established or what amount of water was unappropriated. If a right was disputed it could be maintained only by force or by a tedious suit at law. This unsatisfactory state of affairs continued until 1889, when the first irrigation law was enacted. The method of establishing a claim for water under this law was as follows:

(1) A notice, stating the amount appropriated and the purpose of the appropriation, was posted by the claimant at the point of diversion.

(2) A copy of the notice was filed with the county clerk in the county in which the appropriation was made within ten days after posting.

(3) The work of construction was to be begun within sixty days after posting and prosecuted with diligence to completion. By compliance with these rules the right dated back to the time of posting notice. To prevent speculative filings, the law prescribed that a failure to observe these rules forfeited all rights as against a subsequent appropriator who made full compliance with the law; that is, the right of the claimant who failed to take the steps required by the law did not relate back to the date of posting, but was determined by the date when water was first applied to a beneficial use.

No provision was made limiting the amount appropriated by the respective claimants, neither was there any provision for the distribution of the water, nor for the protection of the appropriators. Under this law the records of the county clerks soon showed the waters in most of the streams in the State appropriated many times over. Many of the streams of the State cross several counties. The record in each county showed only the filings made in that county, and there was no means of determining the total appropriation from such a stream except by an investigation of the records of every county through which the stream flowed. The filings in a single county would often show more water appropriated than could be found in the stream, even in time of flood. The would-be appropriator could disprove this record only by a careful examination of all the territory susceptible of irrigation from the stream. This was a tedious, expensive process, impracticable for the small appropriator. The result was a condition of hopeless confusion and discouragement for the real appropriator. With slight modifications in 1891 this law remained in force until 1895, when the present law was enacted.

The statute of 1895 reaffirmed the validity of prior rights through

use and made a formal statement of the doctrine of State ownership of water.

Water divisions.—The State was divided into two water divisions. Water division No. 1 includes the basin of the Platte and its tributaries west of the mouth of the Loup River, and all lands south of the Platte drained by streams not tributaries of the Platte.

Water division No. 2 includes the basins of the Loup, White, Niobrara, and Elkhorn rivers and their tributaries, and all other lands not included in Division 1.

State board of irrigation.—By this law a board of irrigation, consisting of the governor, attorney-general, and commissioner of public lands and buildings was created. The governor is ex-officio president of the board. The law provides for a secretary and an assistant secretary of the board, an undersecretary for each of the two divisions, and such underassistants as shall be found necessary for the proper distribution of the water. The term of office in each case is two years. The secretary or State engineer is the executive officer, his acts being subject to review by the board. It is made the duty of the board through its secretary: First, to pass upon and fix the priority and amount of all claims which had been initiated prior to April 4, 1895; second, to pass upon all applications for permits to make appropriations of water under the existing laws; and third, through the undersecretary and his assistants to distribute the waters in accordance with the priorities and amounts determined by the secretary and approved by the board.

The law made it the duty of the county clerks to forward copies of all filings made for water prior to April 4, 1895, on record in their respective offices. These, with the claims filed with the board of irrigation by parties who had neglected to post notices and file with the county clerks, but who had appropriated and used the water, made up the claims to be adjudicated before there could be any intelligent disposition of the new appropriations, or any equitable distribution of the water could be made.

Since the organization in April, 1895, 994 claims and contests under the old law have been placed on record with the board. The steps in the process of an adjudication are:

(1) Copies of the county records of claims are obtained from the county clerks.

(2) Each claimant is required to file a claim affidavit setting forth all important facts, with the history of the appropriation, and a plat showing the location of the stream and ditch and the territory irrigated. To secure uniformity and definiteness, blanks are furnished by the board.

(3) Hearings are appointed at points convenient to the claimants for the taking of oral testimony in support of this claim. This oral testimony is transcribed and made part of the record. A copy of the original filing (if there is one), the claim affidavit, and the tran-

script of the oral testimony, with other affidavits and documents furnished by the claimant, with the report of a responsible engineering assistant after a personal inspection of the works, constitute the record in each case, and on this the decisions of the secretary are based. In determining the rights of these claimants the board is guided by the following principles: Where a notice has been posted at the point of diversion, a copy filed with the county clerk, and the law complied with as to diligence in construction, the priority is fixed by the date of posting notice at the point of diversion. When there is an evident lack of diligence the priority dates from the time when beneficial use began. When there is no filing the priority likewise dates from the time when use began. The maximum allowance is 1 cubic foot per second for each 70 acres of land brought under irrigation. The amount is limited by the capacity of the ditch. When the capacity of the canal is in excess of the acreage covered the area determines the allowance. At the time of the passage of this law many of the younger claims begun under the old law were in an unfinished condition, and in passing upon these it has been necessary to fix a time for the completion of the appropriation. The opinion issued in such a case determines the priority, but conditions the amount of the grant on the capacity of the ditch and the area actually irrigated at the expiration of the time fixed by the secretary. The time allowed for completion varies with the character and extent of the work. The determining of the rights under these claims has presented many perplexing problems and has claimed much of the time and attention of the secretary and his assistants; but this part of the work is now rapidly approaching completion, except in contested and belated cases, and in the future the work of the secretary and his assistants can be given more largely to the new appropriations and to the economical and equitable distribution of the water.

Appeals.—Claimants dissatisfied with the decision of the secretary may appeal to the board, and a further appeal may be taken from the finding of the board to the district court of the county in which the point of diversion is located.

Appropriation under existing laws.—All unappropriated waters of any natural stream in the State are subject to appropriation. Priority in appropriation gives the better right as between those using water for the same purpose, but appropriations for domestic use take precedence over appropriations for power purposes.

How appropriations are secured.—The steps in the process of securing a right to use water are as follows: The person desiring to acquire a right to the use of water files with the State board an application for permit to make the appropriation. This application is made on a blank form furnished by the board, and sets forth in the form of an affidavit the important facts concerning the desired appropriation. If, on examination, the application is found to be properly prepared, the filing is put on the record. If not, it is returned for correction, and the appli-

cant acquires no right till the filing is made in proper form. If there is unappropriated water in the stream and the appropriation is a proper one, the board, through its secretary, approves the permit, authorizing the applicant to take such steps as may be necessary to perfect the appropriation. If the secretary deems the amount applied for excessive, he may limit the appropriation to a less quantity. If there is no unappropriated water in the sources applied for, or an appropriation has been perfected to water the same land, it is the duty of the secretary to refuse the permit. In these matters, as in the case of the claims, the acts of the secretary are subject to the revision of the board, and an appeal may be taken from the decision of the board to the district court. Within six months after the approval of the appropriation a plat must be filed on a scale of not less than 2 inches to the mile, showing the location of the stream, the location of the canal, and the legal subdivisions of land to be watered. The work of excavation and construction must be begun within six months after approval of the application and carried forward diligently to completion. When the appropriation has been perfected in accordance with the law a certificate is issued, signed by the president of the board and the secretary, setting forth the priority and amount and the lands for which the appropriation is perfected. This certificate is forwarded to the county clerk of the county in which the appropriation is made, is recorded by him, and transmitted to the applicant.

The priority of the appropriation dates from the filing of the application with the State board.

Nature and limitations of appropriations.—The importance of this topic has not as yet been fully realized, but it is one that is making itself felt more and more as the value of rights to the use of water increases with the increased use and the consequent diminished supply. The act of 1889 prescribed that all appropriations must be for beneficial use, and that the purposes and places of use should be described in the notices posted at the point of diversion. The notices were, however, in most cases very vague and imperfect in their description of place and use. The act further prescribed that when the use ceased the right should cease. The law of 1895 went still further and required that a description of the land to be irrigated should be given with a plat showing its location. The theory of the board is that in all these laws the purpose of the legislature has been to attach the right to the use of water to the land. This has not, however, as yet come to an issue, though there are cases on the docket now that are likely to raise the question of the right of the appropriator to transfer his water right from one piece of land to another. The law of 1889 limits the appropriation in all cases to the amount required by good husbandry for the cultivation of the crops. The law of 1895 makes the same limitation and fixes a maximum limit of 1 cubic foot for each 70 acres irrigated. There is much difference of opinion and some

difficulty in determining the proper amount. The climatic conditions vary from the humid in the east to the arid in the extreme west, and the soil conditions vary as widely as the climatic; so that much must be left to the judgment of the person who distributes the water.

Since April 4, 1895, there have been filed with the State board 460 applications for water, covering some 3,000,000 acres. It was evident at the beginning of the work under the new law that the claims under the old law would demand the time of the board for some time, and that it would be impossible to determine until these claims were adjudicated what water was appropriated or what land was already covered by canals already built or in process of construction. Not desiring to stand in the way of construction where appropriation could properly be made, a circular letter was issued by the board and mailed to each new applicant when he made his filing, setting forth the facts as to the work before the board and as to the time that might be required before his application could be reached. He was informed of the uncertainty as to there being water for his appropriation, and was notified that he would not be held responsible for beginning his work until after his appropriation had been approved, but he was further notified that if he felt sure there was unappropriated water in the source of supply the board would not seek to prevent his proceeding with the construction, and that such construction should not in any way prejudice his appropriation. In many cases the canals have been built; others await the action of the board.

As fast as the claims under the old law can be gotten out of the way, the applications under the new law are taken up and passed upon. It has been found necessary in most cases to make a personal inspection of the proposed location and the lands to be irrigated. When the supply is sufficient and the plan appears reasonable and feasible the grant is made. If otherwise, the application is either rejected or modified to fit the conditions.

Water divisions and water districts.—The two divisions into which the State is divided by the law, viz, water division No. 1 and water division No. 2, are subdivided as follows:

Division No. 1A, the Platte and its tributaries west of the Loup.

Division No. 1B, the Republican and its tributaries west of the Loup; division No. 1C, the Little Blue and its tributaries; division No. 1D, the Big Blue and its tributaries; division No. 1E, the Lodge Pole; division No. 1F, the Great and Little Nemeha and their tributaries and the tributaries of the Missouri south of the Platte.

Division 2A, the Loups and their tributaries; division No. 2B, the Elkhorn and its tributaries; division No. 2C, the Niobrara and its tributaries; division No. 2D, White River and its tributaries; division No. 2E, Hat Creek and its tributaries; division No. 2F, all tributaries of the Missouri except the Niobrara north of the Platte.

For convenience in the distribution of water, water districts are cre-

ated. Those districts, when the territory covered is not too great, are made up of a single basin or division. When a division covers more territory than can be properly administered by one assistant, the territory is subdivided into districts of convenient size for the distribution of water. For each district so created an under assistant is appointed. He receives his appointment from the board, works under the direction of the under secretary for his division, and is paid by the county for which service is rendered. Five such districts have thus far been created and assistants appointed. These districts are:

Water district No. 1, water division No. 1A, including the waters of the North Platte River and its tributaries in Keith and Deuel counties.

Water district No. 2, in water division No. 1A, including the waters of the North Platte and tributaries in Cheyenne and Banner counties.

Water district No. 1, water division No. 1B, including the waters of the Republican River and its tributaries in Red Willow, Hitchcock, Hayes, Chase, and Dundy counties.

Water district No. 1, water division No. 1E, including the waters of Lodge Pole Creek and its tributaries in Deuel, Cheyenne, and Kimball counties.

Water district No. 3, water division No. 1A, including the waters of the Platte River and the North Platte and South Platte rivers and their tributaries in Buffalo, Kearney, Phelps, Gosper, and Lincoln counties. (For boundaries and locations of these districts see Pl. III, p. 36.)

Enlargement and extension of ditches.—When it is desired to enlarge or extend old ditches so that a larger appropriation is needed, an application is required as for a new appropriation. When changes in the location of headgate become necessary, a petition is filed for permit to make such change.

Storage of water.—Water not needed for immediate use for irrigation or for domestic use may be stored in reservoirs. For this purpose an application is made as for other appropriations.

Dams.—For dams less than 10 feet high, no special permit is required. For a dam over 10 feet in height, plans must be submitted to the secretary for examination and approval.

Fees.—No fees are required for any work done by the State board except for a stenographer when the secretary is conducting a hearing in the adjudication of claims. The stenographer's fee is 20 cents per folio, to be paid by the party in whose interest testimony is given.

The law is working well. The confusion which existed when the law of 1895 came into force is rapidly disappearing. The experience of the three years just past has revealed the necessity for some minor changes, but on the whole the law is working satisfactorily.

WATER LAWS OF NORTH DAKOTA.

Judging from its statutes, North Dakota can not be considered as an irrigation State, the Revised Code of 1895 containing only two paragraphs relating to this subject. In this respect it is in striking contrast to South Dakota, with its comprehensive code of laws designed to promote irrigation from artesian wells. There are no laws for the recording or establishment of titles to water by appropriators. The constitution makes all the streams and natural water courses public property.[1] But the owner of the land is made the owner of the water standing thereon or flowing over or under its surface where it does not form a definite stream. The right to divert and appropriate water from streams is nowhere recognized. The doctrine of riparian rights is a part of the law of this State, and it does not seem to have in any way been modified.[2]

WATER LAWS OF SOUTH DAKOTA.

In 1881 the Territory of Dakota enacted a water-right law which provided that—

> Any person or persons, corporation or company, who may have or hold a title or possessory right to any mineral or agricultural land within the limits of this Territory shall be entitled to the usual enjoyment of the waters in streams or creeks in said Territory for mining, milling, agricultural, or domestic purposes; provided, that the right to such use shall not interfere with any prior right or claim to such waters when the law has been complied with in doing the necessary work.

It also provided that any person or company appropriating water should construct at least 20 feet of ditch or flume within thirty days of the first act of appropriation and turn the water therein from the channel of the creek or stream and in addition construct at least 20 rods of said ditch if needed and turn the water therein within six months from the date of appropriation. It required the locator within twenty days from the date of location to file a certificate of location with the registrar of deeds in the proper county. A copy of such certificate was also required to be posted at the head of the ditch.

Failure to begin work within sixty days after location and to prosecute such ditch or canal or flume to its final completion without unnecessary delay was deemed an abandonment. The Dakota Territorial laws also provided for the organization of ditch companies for the purpose of irrigation. The articles of incorporation of such companies

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[1] Sec. 210, art. 17, State constitution North Dakota. All flowing streams and natural water courses shall forever remain the property of the State for mining, irrigating, and manufacturing purposes.

[2] Sec. 3362, chap. 27, Civil Code. *Land includes water.*—The owner of the land owns water standing thereon or flowing over or under its surface but not forming a definite stream. Water running in a definite stream formed by nature over or under the surface may be used by him as long as it remains there; but he may not prevent the natural flow of the stream or of the natural spring from which it commences its definite course, nor pursue nor pollute the same.

were required to specify the stream or streams from which water was to be taken, the point or place on the stream at or near which the water was to be taken out, the line of the ditch as near as might be, and the use to which the water was to be applied, and required every ditch corporation to furnish water to the class of persons using water in the way and for the purpose for which the articles of incorporation declare the water obtained to be used. Whenever they have water in their ditch unsold they were required to give preference to the use of water to the class of persons named in the articles of incorporation, whether manufacturers, miners, or farmers.

Corporations formed under this act were required to commence construction of works within ninety days and to prosecute the same with due diligence until completed, the time of completion not to extend beyond a period of four years.

Since the admission of South Dakota to statehood there has been little legislation regarding the use of surface waters. There are no constitutional provisions relating to water rights and no State laws of any importance governing appropriations from streams. Subterranean waters have received far more consideration from the State's law makers than that found on the surface. Although the Missouri, Belle Fourche, and Cheyenne rivers are important streams and are extensively utilized in irrigation, the State has made no provision for the legal establishment of rights to their waters.

There have been but few attempts to establish or enforce priorities of right to underground waters, but the exceptional volume of the subterranean supply in South Dakota has caused this State to declare that such rights exist and to authorize interference with the construction or operation of wells which threaten to diminish the flow of those sunk at an earlier date. There is a wide difference between governing the diversion and use of a stream whose source and volume can be readily determined and governing a subterranean one, whose source, extent, and duration are all matters of conjecture. It is therefore somewhat remarkable that the legislation of this State, which provides for the restricting of the number of wells in a township, for their location by public officers according to some prearranged or systematic plan, and for the distribution of the water supply by public officials, has gone further than have those of other States in regulating the distribution of a visible supply.

The only law relating to surface streams was enacted in 1897, when two declarations were made appropriating these waters to public uses. The first of these reads as follows:

"That all surface waters in the State of South Dakota are hereby appropriated to the use and benefit of the public."[1]

In a law approved by the governor four days after the one just quoted there is a material restriction upon the dedication to public

[1] Sec. 1, chap. 75, Session Laws, 1897.

use; the first section of the law last enacted being "That all surplus water, above the normal amount in lakes, rivers, creeks, or other bodies of water, is hereby appropriated to the use and benefit of the people of this State."[1]

The expression "above the normal amount" at once raises the question as to what is to be considered the normal flow of a river or the normal depth of water in a lake. If it is simply the right to divert the surplus during the flood season the right is of little value for direct irrigation. Crops need water as badly in July, when streams are low, as in June, when they are at their flood, and a right which would terminate before they are matured would hardly be worth acquiring. How far the later law will serve to modify or restrict the right to take water from streams to store in reservoirs for use in irrigation[2] only a judicial interpretation can determine; but, taking all the facts togetner, it would appear that the people of this State have not looked with favor on any serious diminution of surface streams by irrigators. If the supreme court should decide in the case now before it[3] that the common-law doctrine of riparian rights prevails the construction of large canals will be attended with serious risk.

Rights to underground waters.—No such uncertainty exists regarding the use of subterranean waters. Any person, corporation, or company can construct artesian wells on land that they own or control, and can under certain conditions store, lease, or sell the waters thus obtained.[4] There are no restrictions on the rights of private parties to make wells on their own lands for their own use in irrigation, manufacturing, or domestic purposes, but since 1895 the right to appropriate water for other purposes is not recognized where such appropriation will reduce the flow of adjacent wells.[5]

The location of private wells is also subject to State supervision in order that the most recent ones may not reduce the flow of those already constructed.[6]

The construction of artesian wells is not, however, left entirely to private enterprise. The laws of the State provide for their construction and control by townships and incorporated villages. While the amount of money invested in this sort of development is far less than the debt incurred through the sale of bonds under the Wright act in California, yet so far as the principle of State aid and control is concerned it is an advance on the legislation of any other State, and the results will be followed with much interest by other arid commonwealths.

The water from these public wells may be used for the purposes of irrigation and for domestic purposes. As the latter term is very differently construed in many of the arid States, it is of interest to notice the limitations placed upon the term in the Dakota law. It is defined

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[1] Sec. 1, chap. 77, Session Laws, 1897.
[2] Sec. 1, chap. 104, Session Laws, 1895.
[3] Farwell *v.* The City of Sturgis.
[4] Secs. 1, 2, 5. 18, 19, chap. 103, Laws, 1890.
[5] Sec. 42, chap. 80, Laws, 1895.
[6] Secs. 43, 44, 46, 47, chap. 80, Laws, 1895.

to mean for household use, for the supply of domestic animals kept with and for the use of the household and farm, and the watering and sustaining of trees, grass, flowers, and shrubbery about the house of the consumer in an area not exceeding one half acre of land. Water may also be used for manufacturing purposes whenever such use will not in any manner obstruct or materially diminish the water for irrigation purposes, but a license for such use shall not be for a period to exceed ten years.

The water from these public wells may also be used for the filling of reservoirs, unless in the judgment of the authorities such use tends to diminish the flow of other wells used exclusively for domestic and irrigation purposes.[1]

No provision has as yet been made for determining or establishing priorities of right between wells constructed at different periods, but the later legislation seems to indicate that the superior right of the wells first dug is recognized, and should the increasing demand result in a diminished flow, it seems reasonable that in the evolution of water laws, which has already taken place, the next step will be to follow the practice adopted in regard to the use of water from streams and recognize the superior right of the wells first constructed.

WATER LAWS OF WYOMING.

Historical.—Water rights preceded water laws in Wyoming Territory. When the first statute giving the right to take water from streams was enacted about one hundred ditches were already doing this.

This law was passed in December, 1875. It gave parties owning or claiming land along a stream the right to take water therefrom to irrigate it, and provided that when there was a scarcity on any stream the county commissioners of the county where complaint was made should appoint three commissioners to divide the supply among those needing it. This law only provided for the use of water in irrigation. No record of either claims or appropriations was required, nor did priority of use give the better right, as it does under present laws. The last man to file on land along a stream had the same right to its use as the first settler. In dividing the flow the three commissioners were required to allow each user all he needed part of the time rather than an inadequate supply all of the time, the diversion being by time rather than by volume.

In many respects it was an admirable beginning for an irrigation system, but it had one weakness which led to its failure and ultimate repeal. It did not fix the salary of commissioners and made no provision for paying for their services. Its most interesting features were the abrogation of the doctrine of riparian rights, making the ownership of land rather than the construction of ditches the basis of a right

[1] Secs. 2, 3, 4 18, 19, 20, 21, 22, 23, 30, 32, 34, 35, 36, 37, chap. 80, Session Laws 1895.

to water; placing all rights on an equal footing, and requiring streams to be divided by time rather than by volume.

For eleven years after its passage water-right legislation rested, but in 1886 a radical change was made by the adoption of what was intended to be a complete irrigation code. The new law not only made radical changes in methods, but the departure from original principles was equally great. Under the original law, ownership or control of land was the basis of all rights to use streams; under the later one the ownership and irrigation of land were both practically ignored. The building of ditches became the foundation of water rights, and the leading if not sole test of an appropriation. The original doctrine of the equal rights of all users gave way to priority of appropriation, the dates of such priorities being fixed by the time when the ditch on which the claim rested was begun.

These two changes made a record of existing ditches indispensable, and elaborate provision was made for this. Claims for existing ditches had to be filed with the clerk of the district court, claims for new ditches with the county clerk. The county surveyor of each county was required to measure every ditch in that county, issue a certificate of its capacity, which had also to be recorded. The surveyor's charges and all these recording fees had to be paid by the ditch owner. It made a heavy tax, and as the results were not satisfactory the law soon became very unpopular. The claims made were ex parte, and were usually for extravagant amounts. The surveyor's charges were in some cases outrageous and his certificates of little value, being often made out without even a visit to the ditch. In no instance was there an actual measurement of the volume diverted.

After all these fees had been paid, users had no way to enforce their rights. For all practical purposes they were in the same condition they were at the outset. Before anyone could close the headgates of late appropriators, rights had to be adjudicated in the district court. This court was the real authority. Its decree was the sole guide to the commissioner and the basis of all public or private control. The procedure was copied from that of Colorado and was open to all the objections urged by Judge Elliott in the portion of his brief heretofore quoted. The court could not begin an adjudication. When begun by private parties it was simply a contest for the ownership of public property in which public interests were not represented. Nor was the procedure satisfactory to users. It was too expensive. In the five years of this law's existence only six decrees were rendered.

Two years later the law was modified and greatly improved by doing away with the certificates of county surveyors and with requiring claims to be recorded in the district court. The office of Territorial engineer was created. Some needed limitations were placed on speculative rights claimed by ditch builders, and rights for domestic uses were made *superior to all others*, regardless of the time when acquired.

In 1890 Wyoming became a State, and this change was utilized to reform the water laws. The code of 1886 was an admitted failure. It had no administrative head; there was no central record of ditches or of appropriations; claims against a single stream were often divided between three or four counties. The burden of recording fees had produced a hostility to all irrigation legislation, and the cost of adjudicating rights in the courts was so great that the settlement of controversies was not keeping pace with their creation. The authority of the Territorial engineer was nominal, not real. He had no oversight over the building of ditches or voice in the establishment of rights. Five officers or tribunals, elected to perform other duties and with little or no knowledge of the needs of users, had to deal with water-right questions before they reached his office. The result was chaos, which all recognized should be ended.

The water-right complications which preceded statehood made irrigation one of the leading questions of the constitutional convention. Its members were unusually well informed, both as to the obstacles to be overcome and the need of adequate laws. The constitution, therefore, took advanced ground on these questions. All public water was made the perpetual property of the State. A special tribunal, called the State board of control, was created to manage this property. The State was divided into four water divisions, based on drainage lines, and a superintendent provided for each, these four superintendents and the State engineer forming the board of control. The State engineer is its ex-officio president. In addition to his duties as a member of that board he is the head of the administrative control of streams, and all appropriations therefrom are subject to his examination and approval. The law which carried these provisions into effect was passed in December, 1890, and is still in force.

Territorial claims.—The foregoing is a brief outline of the legislation under which rights to water have been acquired. It now remains to explain the number and character of these rights.

About 3,000 claims to the water of over 600 differently named streams and springs were recorded before Wyoming became a State. On six of these streams court decrees have fixed the priorities and amounts of appropriations. The other 594 had to be dealt with by the State board of control. Many of these were overappropriated, and the scarcity in the supply made an early settlement of its ownership of great importance. The determination of these unsettled rights has, therefore, been the leading feature of the work of the board of control, taking more of the time of its members than all its other labors combined. Lack of accurate records or of satisfactory evidence makes the determination of priorities laborious and difficult, and it is not yet completed. There are still many streams on which not a single right has been confirmed and established There exist, therefore, three classes of Territorial rights—those established by court decree, those determined by the board of

control, and the inchoate or unsettled rights based on statements of claim.

The titles to water conferred by adjudicated rights are not the same; on the contrary, they differ widely in character. Those established by court decrees are not attached to any particular tract of land. In some even the ditch is not named. The owner of the ditch is apparently the absolute master of its decreed capacity. Rights established by orders of the board of control attach to the lands irrigated, which are in all cases described. The ditch through which the water is diverted is also named, it being the theory of the board that even the right of use is restricted to the place and purpose for which it was acquired.

Statements of claim which have not been adjudicated can only be considered as showing a probable right. In but few cases is either the ditch or the use for which the water is claimed properly described. Nearly all claims are for excessive amounts.

The amounts and priorities of Territorial appropriations, established by the board of control, have been based on the following evidence:

Measurement of the stream and of ditches taking water therefrom.

Surveys of the ditches to show the land irrigated or capable of being irrigated.

Proof of the beneficial use of water by the appropriator.

Records of Territorial claims, transcripts of all these records having been furnished the State engineer.

In determining these rights the board has been guided by the following principles:

Priority dates from the survey of ditches if such survey is followed promptly by construction and the beneficial use of the water diverted.

Where proper diligence is not shown priority dates from the time of use.

The amounts of appropriations are fixed by the volume actually applied to beneficial use. In irrigation this is computed from the acreage of land reclaimed.

Where many irrigators take water from one ditch or canal, each one files separate proof and separate certificates of appropriation are issued. No appropriations are issued to ditches or ditch owners separate and apart from the use by which the right was acquired. Forms of proof and of certificates of appropriation are given in the second bulletin of this series (No. 60).

Appropriations made since Wyoming's admission to statehood.—Between January 1, 1891, and July 1, 1898, 1,865 applications for appropriations of water through new ditches and 350 applications to enlarge or extend old ones, have been filed with the State engineer.

The conditions attached to the majority of the earlier permits have been complied with and certificates of appropriation have been issued. A large number have been canceled, owing to failure of applicants to either begin or complete work within the time designated in the permit.

As a rule, small individual ditches have been built. All of the large projects started prior to the passage of the Carey act in 1894 have been abandoned and the permits therefor have been canceled.

How appropriations are secured.—Anyone desiring to secure rights to unappropriated water is required to file with the State engineer an application for permit to make such appropriation. The form of this application is prescribed by the engineer. Blanks can be had at nearly every printing office in the State, or from the engineer's office.

Permits are required where the existing use of water is to be increased or extended. If a ditch is to be enlarged or extended, or if land not described in an existing right is to be reclaimed, the application must be made and approved in the same manner as where a new ditch is to be built.

Priority of right dates from the filing of the application in the engineer's office, provided the application is made out in proper form. Where not in proper form it is returned for correction, and priority dates from the time the application is received in form for approval.

The failure or neglect of water users to secure rights thereto has resulted in many cases of hardship and loss. Settlers who have ignored the law, under the belief that use alone gave title, have had to accept priorities many years later than they would have been entitled to had the law been complied with. In some cases this has involved the loss of an ample water supply and the enforced acceptance of a precarious one.

The authorities of the land offices require parties making proof of reclamation under the desert act to submit evidence of title to water. Nothing will answer in Wyoming but a permit issued by the State engineer's office. Many learn this at the last moment, when it causes delay and needless added expense.

Form and conditions of applications.—The form of application approved has been changed but once, to conform to an amendment to the law passed in 1895.

Two maps must accompany each application. One of these maps must be on tracing linen, and all maps must be prepared in accordance with the following regulations:

Maps must be drawn to a scale of not less than 2 inches to the mile.

They must show the location of the head gate by courses and distances from some Government corner. They must show the actual location of the ditch or canal, and where Government survey lines are crossed the distance to the nearest corner must be given. (Where corners can not be found, give the location of the survey by courses and distances.)

They must show the course of the stream from which water is taken, the location and area of land to be irrigated, or place where water is to be used for other purposes. (This may be done by marking the boundaries or by coloring the areas.)

Wherever the canal line crosses streams or other ditches the location of such crossings must be shown, and such intersecting streams and ditches must be marked by ink of a different color.

Maps of enlargements or extensions of existing ditches must show the point where such extension begins.

Maps must contain the name of ditch, canal, or reservoir, and the name and post-office of the surveyor, with date of survey.

RESERVOIRS AND DAMS.

Plans of dams, cribs, or embankments must be drawn on a longitudinal scale of not less than 1 inch to 100 feet and for cross sections of not less than 1 inch to 20 feet. Timber, brush, and stone, where used, shall be shown in detailed plans, the scale of which shall be 1 inch to 4 feet. The plans for outlet and waste ways for reservoirs shall be drawn on a scale of 1 inch to 4 feet.

The maps of reservoirs shall show the total area to be submerged and enough levels to permit of computing its capacity.

The fees for examining and recording these applications are as follows:

For filing and examining applications for permits to appropriate water, $2.

For recording statements of claim, $1.50.

For recording applications for reservoir permits, $1.

For recording any other water-right instrument—for the first 100 words, $1; for each subsequent folio, 15 cents.

For issuing certificates of appropriation, $1.

For making certified copies of records, per folio, 15 cents.

For attaching certificate, $1.

Construction of ditches or canals must begin within one year. The time of completion is fixed by the State engineer. In determining this the engineer is guided in part by the wishes of the applicant, but chiefly by the magnitude, location, and cost of the work to be done. The maximum time given is five years, but the engineer can, where good cause is shown, extend the time of construction.

Holders of approved permits are required to report the completion of the ditch or canal and the application of water to beneficial use. After the time of completion has expired parties who have not reported compliance with the conditions of a permit are requested to do so, and if no report is made after a second request therefor the permit is canceled.

Proofs of appropriation under permits.—Notices of the complete beneficial use of water under a permit are filed with the State engineer and submitted by him to the board of control at their next regular meeting. It then becomes the duty of the superintendent of the division where the water is used to ascertain, by a personal survey or the survey of some authorized subordinate, whether the conditions of the permit have been complied with and to take the sworn proof of the appropriator. The report of the examiner and the proof of the claimant are submitted to the board of control at its next regular meeting, and if approved a certificate of appropriation is issued and the title is complete. Rights are, therefore, being constantly inaugurated and established along streams, the aim of those in charge of the State's water supply being to promptly determine all claims. Some difficulty has been experienced in doing this on streams where the Territorial claims have not been adjudicated. Until the priority and amounts of these earlier rights have been determined it is impossible to fix that of the later ones.

Nature and limitation of appropriations.—There is no question of equal importance to western agriculture about which there is so wide difference of opinion as the nature of an appropriation. It will be noticed,

As a rule, small individual ditches have been built. All of the large projects started prior to the passage of the Carey act in 1894 have been abandoned and the permits therefor have been canceled.

How appropriations are secured.—Anyone desiring to secure rights to unappropriated water is required to file with the State engineer an application for permit to make such appropriation. The form of this application is prescribed by the engineer. Blanks can be had at nearly every printing office in the State, or from the engineer's office.

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Maps must be drawn to a scale of not less than 2 inches to the mile.

They must show the location of the head gate by courses and distances from some Government corner. They must show the actual location of the ditch or canal, and where Government survey lines are crossed the distance to the nearest corner must be given. (Where corners can not be found, give the location of the survey by courses and distances.)

They must show the course of the stream from which water is taken, the location and area of land to be irrigated, or place where water is to be used for other purposes. (This may be done by marking the boundaries or by coloring the areas.)

Wherever the canal line crosses streams or other ditches the location of such crossings must be shown, and such intersecting streams and ditches must be marked by ink of a different color.

Maps of enlargements or extensions of existing ditches must show the point where such extension begins.

Maps must contain the name of ditch, canal, or reservoir, and the name and post-office of the surveyor, with date of survey.

RESERVOIRS AND DAMS.

Plans of dams, cribs, or embankments must be drawn on a longitudinal scale of not less than 1 inch to 100 feet and for cross sections of not less than 1 inch to 20 feet. Timber, brush, and stone, where used, shall be shown in detailed plans, the scale of which shall be 1 inch to 4 feet. The plans for outlet and waste ways for reservoirs shall be drawn on a scale of 1 inch to 4 feet.

The maps of reservoirs shall show the total area to be submerged and enough levels to permit of computing its capacity.

The fees for examining and recording these applications are as follows:

For filing and examining applications for permits to appropriate water, $2.

For recording statements of claim, $1.50.

For recording applications for reservoir permits, $1.

For recording any other water-right instrument—for the first 100 words, $1; for each subsequent folio, 15 cents.

For issuing certificates of appropriation, $1.

For making certified copies of records, per folio, 15 cents.

For attaching certificate, $1.

Construction of ditches or canals must begin within one year. The time of completion is fixed by the State engineer. In determining this the engineer is guided in part by the wishes of the applicant, but chiefly by the magnitude, location, and cost of the work to be done. The maximum time given is five years, but the engineer can, where good cause is shown, extend the time of construction.

Holders of approved permits are required to report the completion of the ditch or canal and the application of water to beneficial use. After the time of completion has expired parties who have not reported compliance with the conditions of a permit are requested to do so, and if no report is made after a second request therefor the permit is canceled.

Proofs of appropriation under permits.—Notices of the complete beneficial use of water under a permit are filed with the State engineer and submitted by him to the board of control at their next regular meeting. It then becomes the duty of the superintendent of the division where the water is used to ascertain, by a personal survey or the survey of some authorized subordinate, whether the conditions of the permit have been complied with and to take the sworn proof of the appropriator. The report of the examiner and the proof of the claimant are submitted to the board of control at its next regular meeting, and if approved a certificate of appropriation is issued and the title is complete. Rights are, therefore, being constantly inaugurated and established along streams, the aim of those in charge of the State's water supply being to promptly determine all claims. Some difficulty has been experienced in doing this on streams where the Territorial claims have not been adjudicated. Until the priority and amounts of these earlier rights have been determined it is impossible to fix that of the later ones.

Nature and limitation of appropriations.—There is no question of equal importance to western agriculture about which there is so wide difference of opinion as the nature of an appropriation. It will be noticed

in the historical review of the State laws governing this question, that they were radically changed three times in the first twenty years.

From the limitation of a water right to the irrigation of a specific tract of land, which was all the act of 1875 provided for, to the right to use anywhere or sell to anybody, which the act of 1886 made possible, was a long step toward speculative ownership of streams. The declaration of perpetual public ownership or control made in the State constitution and the attaching of rights for irrigation to the land reclaimed which the State law requires is an equally radical return to the original doctrine. Ditches were dug and rights acquired under each of these laws. If the courts should hold that the law in force when a right was established governs its character, then the limitations of appropriations from the same stream may vary widely. They now do on different streams. In the decree establishing appropriations from Crow Creek, in Laramie County, in 1888, the water is given to the man or company claiming it. Neither the land on which water is to be used nor the ditch by which the water is diverted is located or named.

In the adjudication of water rights from Baldwin Creek in 1888 appropriations are based on the construction of ditches which are named, and the appropriations are attached to these ditches. Neither the acreage nor location of the land on which the water is to be used is set forth. On Crazy Woman Creek the name and dimensions of the several ditches diverting water and the acreage of land to be irrigated are given, but the location of the land is not described. These cover the variations in the court decrees. Following these come the adjudications of the board of control, in which the lands irrigated are described and the amount of the appropriation is based on the needs of the acreage reclaimed rather than on the dimensions of the ditches. The right of any appropriator to continue the beneficial use of water by which a decree of appropriation was secured is unquestioned, but the right of an appropriator to transfer the use of water to some other locality or apply it to a different purpose from the one by which it was acquired is still a subject of controversy in this State. In the case of Frank *v.* Hicks, which involved the transfer of a right acquired under the law of 1886, the court has held that "a right to the use of water for irrigation purposes, together with the ditch or other conduit, may, however, be conveyed separate from the land upon which the water is used." (Wyoming Reports, vol. 4). The authority of an appropriator to separate a water right from the land where acquired, if acquired under the State law, has not as yet been determined further than that the board of control has uniformly ruled that such right does not exist, but that all rights acquired under the State law attach to the lands reclaimed and are inseparable therefrom. This action of the board is based upon the following provision:

Provided, That such an appropriator shall at no time be entitled to the use of more water than he can make a beneficial application of on the lands for the benefit of which the appropriation may have been secured. (Sec. 25, chap. 8, Session Laws of 1890-91.)

In the acceptance of lands granted to the State under the Carey Act it is declared:

That water rights to all lands acquired under the provisions of this act shall attach to and become appurtenant to the land as soon as title passes from the United States to the State. (Sec. 21, chap. 38, Session Laws of 1895).

It is to be hoped that cases may arise under which it will be possible for the supreme court to determine exactly the distinction which exists between the rights acquired under the different laws governing this question. This question has been one of the most perplexing with which the board of control has had to deal in the determination of rights acquired under the Territorial acts. The board has, however, followed the same procedure throughout. It has required parties making proof to describe the land on which the water has been used, and has made the appropriations attach to the lands reclaimed. Corporations or individuals owning ditches, but who are not users of water, have never been granted rights because of such ownership, the proof being made and the appropriations going, in all cases, to the party and use by which acquired. Ditch owners are considered as common carriers entitled to charge for the transportation and delivery of water, but having no authority to sell rights in the stream.

Preferred rights.—Under the law of 1888 appropriations for domestic uses took precedence of appropriations for any other purpose. That is, an appropriation for domestic purposes made in 1890 would take precedence of an appropriation made for irrigation in 1888, the use being superior to the date of acquirement. Only one case has arisen in which this preference has been enforced. This was the case of the Rattlesnake Creek pipe line taking water from Rattlesnake Creek to be used for domestic purposes in a mining town. The law making domestic uses a preferred right was repealed in 1891, and there is no disposition to reenact it. The only preference right which now exists is that of cities and towns to provide for increasing demands due to their growth. Under the constitution they are given the right to condemn and purchase appropriations made for other purposes. (Sec. 5, article 13, State Constitution.)

Rights to stored water.—The law of 1886 contained a provision giving persons constructing reservoirs the right to take and store, from any stream, its unappropriated water, not needed for immediate use. This law made no provision for determining the amount of water stored, nor in any way provided for establishing rights thereto. It did, however, contain a provision which made it inoperative. This was the declaration "that no reservoir shall be constructed or made in or across the channel of any natural or running stream." As this law interfered with the construction of a number of projected storage works it was repealed in 1891. The only law now in force, relating to reservoirs is that which requires the plar State

engineer and authorizes him in case of

construction. There is urgent need

provide for the determination of the amount of stored water and protect the rights of those making improvements of this character.

State control of streams.—The holders of prior rights to a stream are protected in times of scarcity by the water commissioner, who is a sort of police officer with authority to open and close the head gates of ditches and to arrest any user of water who interferes with such head gates after he has regulated the flow through them. Commissioners are appointed by the governor from names recommended by the division superintendent, so that the selection of these officers practically rests with the superintendent. The present governor has appointed whoever the superintendent recommended, and made him responsible for their efficiency. The preceding governor required the superintendent to submit three names, from whom he made his selection.

The jurisdiction of a commissioner is limited to a water district. These districts are created by administrative orders of the board of control. All are bounded by drainage lines, so that a commissioner usually has jurisdiction over a stream and its tributaries. This is not always possible, as the territory covered may be too great for a single man to supervise. In such cases the superintendent has authority to direct concerted action between commissioners dividing parts of the same supply.

New districts are created as necessity therefor arises. There are now 40, divided as follows:

Fourteen in division 1, 7 in division 2, 9 in division 3, 10 in division 4. Some of these districts are too large and will have to be subdivided, as increasing use and growing scarcity make the need of more efficient control more urgent.

Commissioners receive $5 per day for the time actually employed. They can not begin work until their services are called for by two appropriators of the district, and the length of service is limited to fifty days in each season. In important districts this period is too brief, and appropriators supplement the fund provided by law.

Each division superintendent directs the action of commissioners in contested cases, investigates complaints of unfairness, and secures concerted action of commissioners in charge of different tributaries of the main drainage system which each division embraces.

The State engineer is the administrative head of the distribution system. Appeals from the rulings of superintendents are made to his office.

Commissioners are appointed for two, superintendents for four, and the State engineer for six, years. The board of control has always had representatives of both political parties, and three out of the five members have served continuously since its creation.

The same is true of the water commissioners. The sole test has been *honesty* and fitness, and no man who has met these requirements has *ever been removed.*

Where records of titles to water may be found.—Statements of claims, applications for permits, and orders of board of control, in State engineer's office.

Certificates of appropriation, in county clerk's office.

Court decrees, in office of clerk of district court and in State engineer's office.

WATER LAWS OF THE NORTHWEST TERRITORIES OF CANADA.

As has been stated before, a discussion of the water-right laws of the Northwest Territories of Canada has been included to enable those interested to compare the methods of an adjoining country with our own.

These laws are of a twofold character: (1) the general law under which water rights are obtained and enjoyed; and (2) the territorial law relating to the formation of irrigation districts to undertake irrigation as a municipal work.

In considering these laws the first contrast which presents itself is the origin of the general law relating to water rights. This law is an enactment of the Dominion Parliament instead of being the subject of local legislation, and may be compared to an enactment by Congress of an irrigation code for the entire arid West. Under this system the control of both land and water remains under one authority until disposed of to private owners or users. It also avoids the troublesome problem of interstate rights, which now besets a number of localities in the West. This general law, although a Dominion enactment, is administered through the territorial government, the department of public works of that government being the central office of record for applications for water rights, duplicate copies of such applications being forwarded from the territorial department for record at Ottawa, the Dominion capital. The authority administering the law is therefore centrally situated in this arid region, and in direct touch with those desirous of acquiring water rights, while the further safeguard is provided of a record of such rights in the Dominion records.

In Canada admission of a territory to confederation as a Province, or to statehood, as we would call it, is a matter of arrangement between the territorial and Dominion governments, and the provincial constitution is not a matter for expression of opinion by the residents of the territory seeking the provincial status, the rights which can be acquired being closely defined by the British-American act enacted by the Imperial Parliament at the time of the confederation of the eastern Provinces into the Dominion of Canada. The control of the water, except navigable streams, is one of the rights which pass to a Province when entering confederation, but the vacant lands remain within the control of the Dominion; so they, like us, have the divided ownership of land and water, which has caused so much trouble in properly dealing with irrigation in our arid West. In the Northwest Territories they have, how-

ever, the advantage that these water-right laws have been enacted and enforced before the provincial status is reached, and the further advantage that a careful record of all these rights granted is a part of the territorial records.

The water of streams and lakes, like the public land which borders them, is the property of the Crown, and is disposed of under as rigid regulations.

Riparian rights, except for the needs of users for domestic purposes, are not recognized. A user of water away from a stream has the same right thereto for irrigation as the owner of land along its banks. The significance of the fact that a part of the British Empire has promptly recognized the need of abrogating the common law doctrine of riparian rights ought to be recognized by those States which are demoralizing irrigated agriculture by attempting to retain it. The clause which defines the extent of governmental ownership is given entire:

> The property in and the right to the use of all the water at any time in any river, stream, water course, lake, creek, ravine, canyon, lagoon, swamp, marsh, or other body of water shall, for the purposes of this act, be deemed to be vested in the Crown, unless and until and except only so far as some right therein, or to the use thereof, inconsistent with the right of the Crown, and which is not a public right or a right common to the public, is established; and, save in the exercise of any legal right existing at the time of such diversion or use, no person shall divert or use any water from any river, stream, water course, lake, creek, ravine, canyon, lagoon, swamp, marsh, or other body of water otherwise than under the provisions of this act.

The purposes for which water may be acquired are divided into three classes: First, domestic purposes, which include household, sanitary purposes, the watering of stock, and all purposes connected with the working of railways and factories by steam. This does not include the sale or barter of water for such purposes. The second class is rights for irrigation, and the third for other purposes; but no application will be granted where it will deprive any person of the use of water from the stream for domestic purposes.

Method of acquiring rights and character of records.—It will be seen that this law recognizes the importance of titles to water and at the outset impresses it on intending users by the care which is manifested by having the preliminary application give in detail all of the facts on which the right is to be ultimately measured. There are no ex parte claims of more water than streams carry without map of ditches or description of land. There is no recording of claims without examination or correction. Instead of the characteristic procedure of the arid States, there is all the order and method that marks the disposal of public land by the General Government.

The applications for a license to divert and use water from any source must set forth in the fullest detail the names of officers and shareholders, in the case of companies, or the names of the individuals where the *applicant* is not an incorporated company, their post-office addresses,

their proposed plans, and their financial ability to carry out the projected work. There must be maps and plans giving in detail the location of projected ditches and the location and acreage of land to be irrigated. Simple filing of the applications does not end the matter, as it does in many of the arid States. They must be examined by some qualified officer, and if not correct must be corrected and a copy of the corrected plans filed for public inspection in the central office in the Territory and another with the department of the interior at Ottawa.

In addition to this application, in all ditches intended to divert over 10 cubic feet of water per second a public notice must be given in one issue of the Canada Gazette, and another notice once a week for a period of not less than thirty days nor more than ninety days in a newspaper in the neighborhood of the proposed works. The superiority of a notice of this kind to the plan adopted by some of the arid States of posting a notice on a stake in some lonesome bend of the stream does not need to be dwelt upon.

In cases of ditches of less that 10 cubic feet capacity a newspaper notice is required for thirty days. The purpose of this preliminary newspaper notice is to give those whose interests will be injured by the proposed diversion an opportunity to protest to the authorities of the government, and no work is permitted to be begun until parties have had an opportunity to be heard and until the government has rendered its decision on the merits of the proposed use. After this, work is not permitted to be begun until the approval of the government has been signified, with such changes as the government has seen fit to order. The authorization issued specifies a time in which the work shall be completed, and it is the final authority for proceeding with the work, and the construction of the works is subject to inspection by a government official at any time during their progress. To appropriators of water in the arid States, accustomed to the careless methods which generally prevail, this may seem like a slow and vexatious preliminary, but experience has already shown that a neglect of these precautions at the outset involves ten times as great an outlay afterwards in the effort to unravel the tangle which our lack of definite records creates. It has, moreover, this very marked advantage: That the privilege is definite, and one can tell before entering upon it exactly what is required and when the legal formalities may be completed. Our method of leaving everything for a final settlement in the courts is not only an injustice to these tribunals, but places every irrigator in a position where he neither knows what the expense of a final settlement of his title is to be nor when that expense will end.

Ditches authorized under this act must be begun within two months after the publication of the last notice, unless this time falls between the 1st of November and 1st of the May following, but when this occurs the time shall date from the 1st of May following. The time for completion is fixed by the government, which, however, has authority *to extend this for any* reason which may be deemed sufficient.

The amount of the appropriation is limited by the capacity of the works, which is determined by an inspection ordered by the minister of the interior, and the report of this inspector is made conclusive. This is believed to be a mistake. The experience of the arid States of this country has shown that making the ditch builder the appropriator of water does not afford sufficient security to the user. It is not the ditch builder who makes the principal return nor whose interests are of enduring moment; it is the man who reclaims the land and makes his home thereon who should receive the first consideration of the law-makers who deal with the subject. Making ditch builders or canal companies the appropriators of water threatens to put users of water from those canals under a perpetual mortgage to them.

The priorities of rights of the different parties receiving license to acquire water for irrigation are determined by the date of approval of these licenses. In case there is not water enough for all it is made the duty of the government to ascertain the facts and to close the head gates of those ditches which are receiving an undue supply or which are taking the water belonging to other ditches by reason of their earlier rights.

The cubic foot per second is made the unit of measurement for running streams, and the acre-foot the unit of measurement for quantity.

In addition to these statutory provisions the government has the authority to make whatever regulations are needed to make its administration effective.

It will be noticed that, taking into account the differences involved in having one system under State authority and the other under the authority of the general government, the irrigation law of Canada bears a close resemblance to that of Wyoming. In both the distinctive features are the absolute public ownership of the streams; the care exercised in the preliminary steps for the acquirement of title; the fixing by the government, and not by the applicant, of the amount of water to be acquired; the establishment of conditions before a dollar is invested by either ditch builder or water user, and, finally, the celerity and cheapness with which rights are established after the work is done and the care and efficiency with which the government protects these rights when once established. In both cases they are irrigation systems which arrive somewhere. In neither is the court required to become an agency to supply the omissions and neglect of lawmakers in the preliminary stages of the establishment of title. Under both systems litigation has been reduced to a minimum, because at every step the irrigator is dealing with specially trained officials who are giving their entire time and thought to the administration of these laws.

U. S. DEPARTMENT OF AGRICULTURE,

OFFICE OF EXPERIMENT STATIONS.

ABSTRACT OF LAWS

FOR

ACQUIRING TITLES TO WATER

FROM THE

MISSOURI RIVER AND ITS TRIBUTARIES,

WITH THE

LEGAL FORMS IN USE.

COMPILED BY

ELWOOD MEAD,

STATE ENGINEER OF WYOMING.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1899.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., January 11, 1899.

SIR: I have the honor to transmit herewith a compilation of abstracts of laws for acquiring titles to water from the Missouri River and its tributaries, with the legal forms in use, prepared by Prof. Elwood Mead, State engineer of Wyoming, in accordance with instructions given by the Director of this Office. This compilation is supplementary to Bulletin No. 58 of this Office on Water Rights on the Missouri River and its Tributaries, by the same author.

This bulletin is respectfully submitted, with the recommendation that it be published as Bulletin No. 60 of this Office.

Respectfully,

A. C. TRUE,
Director.

Hon. JAMES WILSON,
Secretary of Agriculture.

CONTENTS.

LAWS AND LEGAL FORMS FOR ACQUIRING TITLES TO WATER IN THE MISSOURI RIVER BASIN.

INTRODUCTION.

The diversion of water from streams by the irrigators and ditch builders of the arid States has made it necessary to enact laws for the establishment and protection of their individual rights therein. It is essential that the farmer under irrigation look as carefully after his title to a share in the common water supply as he does after his land title. Emigrants from regions of abundant rainfall often fail to recognize the importance of doing this or are at a loss to know what is required to safeguard their interests. Because of this many suffer serious financial loss and the success and orderly administration of irrigation codes are often called in question. Bulletin No. 58 of this series contains a discussion of the water-right laws of those States drained in whole or in part by the Missouri River. It was prepared to aid water users in establishing their rights and to promote the agricultural development of that great region. It directs attention to the need of simpler, cheaper, and more effective methods of disposing of the public water supplies than those which now prevail in some of those States. It is believed that a publication of the laws which that bulletin discusses and the legal forms which irrigators and other appropriators of water must use will be another and valuable aid in removing the anxiety and uncertainty of many to whom the problems of irrigation are new and strange.

Irrigation laws have to deal with many subjects besides the control and division of the public water supply. There are elaborate statutes for the regulation of canals, for the determination of the rights of carriers and users, and for the promotion of new works. From this bulletin all such laws have been excluded in the belief that by separating the laws which govern water titles and public control of streams from all other irrigation legislation a clearer understanding of their scope and purpose would be secured than by a compilation of all the laws. The forms which are given are copies of those now in use and comply with existing laws.

WATER LAWS OF COLORADO.

CONSTITUTION.

Water public property. SEC. 5. The water of every natural stream, not heretofore appropriated, within the State of Colorado is hereby declared to be the property of the public, and the same is dedicated to the use of the people of the State, subject to appropriation as hereinafter provided.

Diverting unappropriated water; priority. SEC. 6. The right to divert unappropriated waters of any natural stream for beneficial uses shall never be denied. Priority of appropriation shall give the better right as between those using the water for the same purpose; but when the waters of any natural stream are not sufficient for the service of all those desiring the use of the same, those using the water for domestic purposes shall have the preference over those claiming for any other purpose, and those using the water for agricultural purposes shall have the preference over those using the same for manufacturing purposes.

REVISED STATUTES.

Priority of right. SEC. 2269. That all ditches now constructed or hereafter to be constructed for the purpose of utilizing the waste, seepage, or spring waters of the State shall be governed by the same laws relating to priority of right as those ditches constructed for the purpose of utilizing the waters of running streams: *Provided*, That the person upon whose lands the seepage or spring waters first arise shall have the prior right to such waters if capable of being used upon his lands.

Reservoirs; right to water; right of way; condemnation. SEC. 2270. Persons desirous to construct and maintain reservoirs for the purpose of storing water shall have the right to take from any of the natural streams of the State and store away any unappropriated water not needed for immediate use for domestic or irrigating purposes; to construct and maintain ditches for carrying such water to and from such reservoir, and to condemn lands for such reservoirs and ditches, in the same manner provided by law for the condemnation of land for right of way for ditches.

Filing statements of claims; ditch, name, description, post-office address. SEC. 2400. In order that all parties may be protected in their lawful rights to the use of water for irrigation, every person, association, or corporation owning or claiming any interest in any ditch, canal, or reservoir within any water district shall, on or before the 1st day of June, A. D. 1881, file with the clerk of the district court having jurisdiction of priority of right to the use of water for irrigation in such water district a statement of claim under oath, entitled of the proper court, and in the matter of priorities of water rights in district No. —, as the case may be, which statement shall contain the name or names, together with the post-office address, of the claimant or claimants claiming ownership, as aforesaid, of any such ditch, canal, or reservoir, the name thereof, if any, and if without a name the owner or owners shall choose and adopt a name, to be therein stated, by which such ditch, canal, or reservoir shall thereafter be known; the description of such ditch, canal, or reservoir, as to location of head gate, general course of ditch, the name of the natural stream from which such ditch, canal, or reservoir draws its supply of water; the length, width, depth, and grade thereof, as near as may be; the time, fixing a day, month, and year as the date of the appropriation of water by original construction, also by any enlargement or extension, if any such thereof may have been made, and the amount of water claimed by or under such construction, enlargement, or extension, and the present capacity of the ditch, canal, or feeder

of reservoir, and also the number of acres of land lying under and being or proposed to be irrigated by water from such ditch, canal, or reservoir. Said statement shall be signed by the proper party or parties.

Proceedings in court; order; evidence; examination; proofs; what facts; decree; certificate of clerk.

SEC. 2403. When, at any time after the 1st day of June, A. D. 1881, any one or more persons, associations, or corporations interested as owners of any ditch, canal, or reservoir in any water district shall present to the district court of any county having jurisdiction of priority of rights to use the water for irrigation in such water district according to the provisions of an act entitled "An act to regulate the use of water for irrigation and providing for settling the priority of rights thereto and for payment of the expenses thereof and for payment of all costs and expenses incident to said regulation of use," or to the judge thereof in vacation, a motion, petition, or application in writing, moving or praying said court to proceed to an adjudication of the priorities of rights to use of water for irrigation between the several ditches, canals, and reservoirs in such district, the court, or judge thereof in vacation, shall, without unnecessary delay, in case he shall deem it practicable to proceed in open court, as prayed for, by an order to be entered of record upon such motion, petition, or application, appoint a day in some regular or special term of said court for commencing to hear and take evidence in such adjudication, at which time it shall be the duty of the court to proceed to hear all evidence which may be offered by or on behalf of any ditch, canal, or reservoir in such district, either as owner or consumer of water therefrom, in support of or against any claim or claims of priority of appropriation of water made by means of any ditch, canal, or reservoir, or by any enlargement or extension thereof, in such district, and consider all such evidence, together with any and all evidence, if any, which may have been heretofore offered and taken in such district in the same matter by any referee heretofore appointed under the provisions of said act above herein mentioned, and also the arguments of parties or their counsel, and shall ascertain and find from such evidence, as near as may be, the date of the commencement of such ditch, canal, or reservoir, together with the original size and carrying capacity thereof as originally constructed, the time of the commencement of each enlargement or extension thereof, if any, with the increased capacity thereby occasioned, the time spent, severally, in such construction and enlargement, or extension and reenlargement, if any, the diligence with which the work was in each case prosecuted, the nature of the work as to difficulty of construction, and all such other facts as may tend to show the compliance with the law in acquiring the priority of right claimed for each such ditch, canal, or reservoir, and determine the matters put in evidence, and make and cause to be entered a decree determining and establishing the several priorities of right, by appropriation of water, of the several ditches, canals, and reservoir [reservoirs] in such water district, concerning which testimony shall have been offered, each according to the time of its said construction and enlargement, or enlargements or extensions, with the amount of water which shall be held to have been appropriated by such construction and enlargements or extensions, describing such amount by cubic feet per second of time, if the evidence shall show sufficient data to ascertain such cubic feet, and if not, by width, depth, and grade, and such other description as will most certainly and conveniently show the amount of water intended as the capacity of such ditch, canal, or reservoir in such decree. Said court shall further order that each and every party interested or claiming any such ditch, canal, or reservoir shall receive from the clerk, on payment of a reasonable fee therefor, to be fixed by the court, a certificate, under the seal of the court, showing the date or dates and amount or amounts of appropriations adjudged in favor of such ditch, canal, or reservoir, under and by virtue of the construction, extension, and enlargements thereof, severally; also specifying the number of said ditch and of each priority to which the same may be entitled by reason of such construction, extension, and enlargements.

Copy of decree; authority of commissioner; recording; copy; evidence.

SEC. 2404. The holder of such certificate shall exhibit the same to the water commissioner of the district when he commences the exercise of his duties, and such water commissioner shall keep a book in which shall be entered a brief statement of the contents of such certificate, and which shall be delivered to his successor, and said certificate, or statement thereof in his book, shall be the warrant of authority to said water commissioner for regulating the flow of water in relation to such ditch, canal, or reservoir. Said certificate shall be recorded at the same rate of charges as in cases of deeds of conveyance, in the records of each county into which the ditch, canal, or reservoir to which such certificate relates shall extend; and said certificate, or

said record thereof, or a duly certified copy of such record, shall be prima facie evidence of so much of said decree as shall be recited therein, in any suit or proceeding in which the same may be relevant.

Clerk publish notice; post copy; ten copies posted by party petitioning.

SEC. 2405. Notice shall be given by the clerk of said court of the time so appointed, by publishing the same in one public newspaper in such county into which such water district may extend, which notice shall be so published in such paper once in each week until four successive weekly publications shall have been made, the last of which shall be on a day previous to the day appointed as aforesaid. Said notice shall contain a copy of said order, and shall notify all persons, associations, and corporations interested as owners in any ditch, canal, or reservoir in such water district to appear at said court at the time so appointed and file a statement of claim, under oath, in case no statement has been before filed by him, her, or them, showing the ditch, canal, or reservoir, or two or more such, in which he, she, or they claim an interest, together with the names of all owners thereof, which statement may be made by any one of the owners of such ditch, canal, or reservoir, for and in behalf of all; and also that all persons interested as owners or consumers may then and there present his, her, or their proofs for or against any priority of right of water by appropriation sought to be shown by any party by or through any such ditch, canal, or reservoir (either as owner or consumer of water drawn therefrom). Ten printed copies of said notice shall be posted in such water district not less than twenty days before the day so appointed, which copies shall be so posted by the party or parties moving the adjudication.

Proof of publication; of posting copies; entry by clerk.

SEC. 2406. Proof of the proper publication of said notice or notices in said public papers shall consist in such case of the sworn certificate of the publisher of such newspaper, showing the publication to have been made in accordance with the provisions of section three of this act, which certificate shall be procured by the party or parties moving the adjudication, at his or their expense, and on said certificate being filed with the clerk, shall enter the amount of the printer's fee therefor as costs advanced by the party procuring the same, which sum shall be counted to his, her, or their credit in distribution of costs. Proof of the posting of said printed copies shall be made by the affidavit of some credible person, certified to be such by the clerk or other officer administering the oath, showing when, where, and how said copies were posted.

Notices served on all parties; how served; notice by mail.

SEC. 2407. The party or parties moving such adjudication shall cause a printed or written copy of the notice aforesaid, published as aforesaid, to be served on every person, association, or corporation shown by the statement of claim on file, as provided in section one hereof; which service shall be made within ten days from the time of the first publication by the clerk, by any credible person certified by said clerk or referee to be such, by delivering such copy as aforesaid to the person to be served, if such person, by due diligence, can be found in the county of his residence. If such person can not be found, as aforesaid, then by leaving such copy at his or her usual place of residence, if he or she have such residence, in charge of some person of the age of fourteen years or over, there residing; and on any corporation, by delivering the copy to the president, or vice-president, or secretary, or treasurer thereof, or the manager or superintendent in charge of their ditch, canal, or reservoir, or authorized agent or attorney, or by leaving such copy at the office or usual place of business of such corporation; and the proof of such service shall be made by affidavit of the person or persons serving said copies, showing when and how such service has been made on such party. In case of parties not served in any manner as aforesaid, the clerk shall deposit in the post-office, duly enclosed in an envelope, with the proper postage stamp thereon, a copy directed to the address of such party, shown in the statement of claim aforesaid, filed by him or her under section one hereof.

Decree; court number all ditches; reservoirs; number appropriations.

SEC. 2408. The court, in making such decree, as aforesaid, shall number the several ditches and canals in the water district, concerning which adjudication is made, in consecutive order, according to priority of appropriation of water thereby made by the original construction thereof, as near as may be, having reference to the date of each decree as rendered, and also number the reservoirs in like manner separately from ditches and canals, and shall further number each several appropriation of water consecutively, beginning with the oldest appropriation, without respect to the ditches or reservoirs by means of which such appropriations were made, whether such

appropriations shall have been made by means of construction, extension, or enlargement, which number of each ditch, canal, or reservoir, together with the number or numbers of any appropriations of water held to have been made by means of construction, extension, or enlargement thereof, shall be incorporated in said decree and certificate of the clerk, to be issued to the claimants, as provided in section one of this act, so as to show the order in priority of such ditch or canal, and of such reservoir, and also of such successive appropriation of water pertaining thereto, for the information of the water commissioner of the district in distributing water; such numbering to be as near as may be having reference to date of decrees as rendered.

When court may appoint referee; what referred.

SEC. 2409. If for any cause the judge of said court shall deem it impracticable or inexpedient to proceed to hear such evidence in open court, he shall, instead of the order mentioned in section four of this act, make and cause to be entered of record an order appointing some discreet person properly qualified a referee of said court, to whom shall be referred the statement of claim aforesaid on file in said matter, the matter of taking evidence and reporting the same, making an abstract and findings upon the same, and preparing a decree in said adjudication; and also in the case of any water district in which a referee has been heretofore appointed, and evidence taken by him under the provisions of this act, the title of which is recited in section four of this act; such evidence so already taken, together with the abstract thereof, and report to the referee who took the same, shall be also referred to said referee, to be appointed as aforesaid, and he shall proceed with his duties as hereinafter provided, first taking an oath of office, such as is required to be taken by referees in other cases under the provisions of the code of civil procedure.

Referee's notice; contents; how published; posting copies.

SEC. 2410. Said referee shall prepare and publish a notice containing a copy of the order appointing him, in which notice he shall appoint a time or times, and place or places, suitable and convenient for the claimants in such water district, at which he will attend for the purpose of hearing and taking evidence touching the priority of right of the several ditches, canals, and reservoirs in said district, and notifying all persons, associations, and corporations interested as owners or consumers of waters [water] to attend by themselves, their agents or attorneys, at the times and places appointed in said notice, and notifying such owners to then and there file a statement of claim in case such statement has not already been filed under the provisions of section one hereof, such as mentioned in section six hereof, and present their proofs touching any priority of right claimed by them for any ditch, canal, or reservoir in said district, which notice shall be published in the same manner and times, and in all respects according to the provisions for publication of newspaper notices mentioned in section six of this act, and proof of such publication shall be made in same manner as is provided in section seven of this act; and he shall also post ten or more printed copies of such notice in ten or more public places in said district, which copies shall be so posted at least twenty days before the time of commencing to take such evidence.

Proof of posting notices.

SEC. 2411. Proof of the posting of said copies shall be made by affidavit of said referee or other person certified by him to be a credible witness, which shall show when, where, and how the said copies were posted, and shall be filed by him with his report.

Proceedings before referee; former evidence; who may offer evidence.

SEC. 2412. Said referee shall attend at the times and places mentioned in his said notice for the purpose therein mentioned, and all persons or associations choosing to do so, and being interested as owners of or consumers of water from any ditch, canal, or reservoir in said district, and may also attend by themselves, their agents or attorneys, before said referee, at some one or more of said times and places so appointed, and shall have the right to offer any and all evidence they may think advisable for their interests in the matter to be adjudicated, as well in districts in which evidence has been heretofore taken as in other districts. All such evidence as has been heretofore taken, if any, in such district, shall be kept present by said referee, subject to inspection by any party desiring to examine the same for purposes of the investigation.

Powers and duties of referee; books and records; evidence.

SEC. 2413. Said referee shall have power to administer oaths to all witnesses and to issue subpœnas for witnesses and subpœnas duces tecum, which subpœnas may be served by any party or constable, or sheriff or deputy sheriff, and may require witnesses to appear at any of the places appointed by *said referee for taking* evidence. He shall permit all witnesses to be examined

by the parties calling them, respectively, and to be cross-examined by any party interested, and he shall take all testimony in writing and note all objections offered to any part of the testimony taken, with the cause assigned for the objection, and shall proceed in all other respects as in case of taking depositions. He shall certify all books and papers offered by any one in his own behalf, and preserve them with the testimony offered concerning the same, and in case of books and papers offered in evidence, which shall not be under the control of the party desiring the evidence for which such books may be offered, said referee shall make a true copy of the parts demanded and certify the same, and preserve the same, together with the evidence offered concerning the same and concerning said books and papers, as part of the evidence in the matter.

Refusal to produce books or papers; effect.

SEC. 2414. No person, association, or corporation willfully refusing to produce any book or paper, if in his or their power to do so, when rightfully demanded for examination and copying, shall be allowed the benefit of any testimony or proofs in his, her, or their behalf, in making final adjudication, if the court shall be satisfied, from all the evidence shown concerning such refusal, that the same was willful.

What facts to be ascertained by proofs.

SEC. 2415. Said referee shall also examine all witnesses to his own satisfaction touching any point involved in the matter in question, and shall ascertain, as far as possible, the date of the commencement of each ditch, canal, or reservoir, with the original size and carrying capacity thereof, the time of the commencement of each enlargement thereof, with the increased carrying capacity thereby occasioned, the length of time spent in such construction or enlargement, the diligence with which the work was prosecuted, the nature of the work as to difficulty of construction, and all such other facts as may tend to show compliance with the law in requiring the priority of right claimed for such ditch, canal, or reservoir; and upon all the facts so obtained shall be determined the relative priorities among the several ditches, canals, and reservoirs, the volume or amount of water lawfully appropriated by each, as well as by means of the construction, as by the enlargements thereof, and the time when each such several appropriations took effect.

Disturbing proceedings; penalty.

SEC. 2416. Every person present before said referee at any time when he shall be engaged in hearing testimony, who shall willfully disturb the proceedings; and every person who shall willfully refuse or neglect to obey any subpœna issued by said referee, when his lawful fees shall be tendered him for his attendance before the referee, shall be guilty of contempt of the court appointing such referee, and on complaint, under oath, of the referee or other person, before the said district court, or judge thereof in vacation, may be brought before the court or judge and dealt with accordingly.

Fees of witnesses; by whom paid.

SEC. 2417. Every witness who shall attend before said referee under subpœna by request of any party shall be entitled to the same fees and mileage as witnesses before the district court in the county in which he shall so attend, and shall be paid by the party requiring his testimony.

Duties of referee; rights of parties; adjournment; notice.

SEC. 2418. The said referee shall take all the testimony offered, and for that purpose shall give reasonable opportunity to all parties to be heard, and may at any place, when the time limited thereat shall expire, adjourn the further taking of testimony then proposed or desired to be offered to the next place in order, according to his published appointments, and at the last place may continue until all testimony shall be taken, or make further appointment at any former place or places as may seem best and most convenient for all parties, giving reasonable notice thereof.

Referee shall examine all testimony; numbering; findings; decree; report.

SEC. 2419. Said referee, upon closing the testimony, shall proceed to carefully examine the same, together with all testimony and proofs which may have been heretofore taken by any former referee in the same district, if any such shall have been taken, under the provisions of said act, the title of which is recited in section four of this act. He shall make an abstract of all the testimony and proofs in his possession concerning each ditch, canal, and reservoir separately, and shall number each ditch and canal in order, and likewise each reservoir, each class consecutively, and also number the several appropriations of water shown by the evidence, all in manner and form as provided in section nine hereof; and shall make a separate finding of all the facts connected with each ditch, canal, and reservoir touching which evidence shall have been

offered; and he shall prepare a draft of a decree in accordance with his said findings, in substance the same as the decree mentioned in section four of this act, and conformable also to the provisions of section nine hereof, so far as the same are applicable, which decree, so prepared by him, shall be returned with his report to the court; and he shall file his report, with said evidence, abstract, and findings, and said decree with the clerk of the court and inform the judge of so doing without delay.

Filing report; court proceed to determine; exceptions; approval; entry.

SEC. 2420. Upon the filing of said report the court, or judge thereof in vacation, shall cause an order to be entered setting some day in a regular or special term of court as soon as practicable, when the court shall proceed to hear and determine the report, at which time any party interested may appear by himself or counsel and move exceptions to any matter in the findings or decree made by said referee; and after hearing the same the court shall, if the decree reported be approved, cause the same to be entered of record, or otherwise, such modifications thereof or other decree as shall be found just and conformable to the evidence and the true intent of this act, and to so much of any and all former laws of the State as shall be adjudged consistent therewith.

Failure to offer evidence; water commissioner disregard claims until, etc.; party obtain decree and present certificate.

SEC. 2421. No claim of priority of any person, association, or corporation on account of any ditch, canal, or reservoir, as to which he, she, or they shall have failed or refused to offer evidence under any adjudication herein provided for or heretofore provided for by said act, the title of which is recited in section four hereof, shall be regarded by any water commissioner in distributing water in times of scarcity thereof until such time as such party shall have, by application to the court having jurisdiction, obtained leave and made proof of the priority of right which such ditch, canal, or reservoir shall be justly entitled, which leave shall be granted in all cases upon terms as to notice to other parties interested, and upon payments of all costs, and upon affidavits or petitions sworn to, showing the rights claimed, and the ditches, canals, or reservoirs, with the names of the owners thereof against which such priority to such ditch, canal, or reservoir has been entered, and certificate, such as mentioned in section four hereof, shall have been issued to claimant and presented to the water commissioner.

Rights of parties against referee for neglect, oppression, etc.

SEC. 2422. Every party interested shall have the right to complain to the court of any act of willful neglect or oppression on the part of the said referee, in exercising his powers under this act, whereby such party shall have been aggrieved, either by refusal of said referee to hear or take evidence offered or by preventing reasonable opportunity to offer such evidence; and the court may order such proceedings in the premises as will give redress of the grievance, at the cost of said referee, if he appear willfully in fault; otherwise in case of accident or mistake costs will be awarded as to the court shall seem just.

Power of court to make just rules; laws construed liberally.

SEC. 2423. The district court, or judge thereof in vacation, shall have the power to make all orders and rules consistent with this act which may be found necessary and expedient from time to time during the progress of the case for carrying out the intent of this act, and of all parts consistent therewith of the said act, the title of which is recited in section four hereof; as well touching the proceedings in court as of the acts and doings of said referee, for the purpose of securing to any party aggrieved by the acts of said referee, or any proceeding of the court, opportunity for redress; and this act shall be construed liberally in all courts in favor of securing to all persons interested the just determination and protection of their rights.

Party must file claim before offering evidence.

SEC. 2424. No persons, association, or corporation representing any ditch, canal, or reservoir shall be permitted to give or offer any evidence before said referee until he, she, or they shall have filed a statement of claim in substance the same in all respects as is required to be filed under the provisions of section one hereof.

Reargument; review; limitation two years.

SEC. 2425. The district court, or judge thereof in vacation, shall have power to order for good cause shown, and upon terms just to all parties and in such manner as may seem meet, a reargument or review, with or without additional evidence, of any decree made under the provisions of this act, whenever said court or judge shall find from the cause shown for that purpose by any party

or parties feeling aggrieved that the ends of justice will be thereby promoted; but no such review or reargument shall be ordered unless applied for by petition or otherwise within two years from the time of entering the decree complained of.

Testimony. SEC. 2426. Whenever testimony shall or may be taken in any district created by this act, for the purpose of procuring decree as to appropriation of water and priorities thereof under the statutes of this State, any testimony theretofore taken before any former referee may be introduced and shall be received as evidence.

Appeals; who may appeal; statement; approval; contents; order; bond; conditions. SEC. 2427. Any party or parties representing any ditch, canal, or reservoirs, or any party or parties representing two or more ditches, canals, or reservoirs, which are affected in common with each other by any portion of such decree, by which he or she or they may feel aggrieved, may have an appeal from said district court to the supreme court, and in such case the party or parties joining, desiring an appeal, shall be the appellants, and the parties representing any one or more ditches, canals, or reservoirs affecting in common adversely to the interests of appellants shall be the appellees. The party or parties joining in such appeal shall file a statement in writing, verified by affidavit properly entitled in such cause in the district court, which statement shall show that the appellants claim a valuable interest in the ditch, canal, or reservoir, or two or more of such, which are affected in common with each other by some portion of said decree, also stating the name or names or otherwise the description of the same, and the name or names or otherwise the description of any one or more other ditches, canals, or reservoirs, which by said decree derive undue advantage in respect of priority as against that or those represented by appellants; and also setting forth the name or names of the party or parties claiming such other one or more ditches, canals, or reservoirs affected in common by said decree adversely to the interest of appellants, and praying that an appeal be allowed against such other parties as appellees. If the court or judge in vacation on examination find such statement in accordance with the statements of claim filed by the parties named as appellees, mentioned in section one of this act, he shall approve the same and make an order to be prepared and presented by the appellants allowing the appeal and showing the name or names of the appellants and appellees, with the name or names or description of the one or more ditches, canals, or reservoirs claimed by the party or parties appellant and appellee, as shown by their several statements of claim filed as aforesaid, before the taking of testimony, and fixing the amount of the appeal bond, which bond shall be executed by one or more of appellants, as principal or principals, and by sufficient securities, and approved by the court or judge in vacation, and shall be conditioned for the payment of all costs which may be awarded against the appellants, or any of them, in the supreme court.

Copy of order served on appellees; publication; posting copies; proof. SEC. 2428. The order last aforesaid shall be entered of record and the appellant or appellants shall cause a certified copy thereof to be served on each of the appellees, by delivering the same to him or her, if he or she may be found, or otherwise serving the same in manner the same as may be at the time provided for serving summons from the district court by the laws then in force, and shall also cause the said order to be published in the same manner as the notices required in section eleven of this act, and proof of the publication in any newspaper shall be the same as in case of said referee's notice, and proof of the posting of the ten printed copies in the district shall be by affidavit of the party posting the same, with the certificate of the clerk of the district court appealed from, that the affiant is a known and credible person.

Transcript to be filed in six months; bill of exceptions. SEC. 2429. The appellant or appellants shall file transcript of record of the district court with the clerk of the supreme court at any time within six months after the appeal shall be allowed as aforesaid. Only so much of the decree appealed from, and so much of the evidence as shall affect the appropriations of water claimed by means of the construction or reenlargement of the several ditches, canals, and reservoirs mentioned in the order allowing the appeal need be copied into the bill of exceptions.

Supreme court amend or make new decree, or remand with instructions. SEC. 2431. The supreme court in all cases in which judgment is rendered and any part of the decree appealed from is reversed, and in which it may be practicable, shall make such decree in the matters involved in the appeal as should have been made by the district court, or direct in what manner the decree of that court shall be amended.

Filing proof of service and notice; sixty days; supreme court makes rules.

SEC. 2432. The said proof of the service and publication of said order allowing the appeal shall be filed with the clerk of the supreme court within sixty days after the making of said order, and if not so filed the supreme court shall, on motion of the appellee or any of the appellees, at any time after such default in filing said proof and before the said proof shall be filed, dismiss such appeal, and if the transcript of record be not filed within the time limited by section twenty-nine of this act such appeal shall, on motion, be dismissed. After the filing of the record and proof of service aforesaid, the cause on appeal shall he proceeded with as the rules of the supreme court, or such special rules as said court may make in such cases, and their order from time to time thereunder may require. Said court shall have power to make any and all such rules concerning such appeals as may be necessary and expedient in furtherance of this act, as well as to preparation of the case for submission, as to supplying deficiencies of record, if any, and for avoiding unnecessary costs and delay.

Court may dismiss referee; vacancy; new appointment.

SEC. 2433. The district court, or judge thereof in vacation, in case of the death, resignation, absence, or other disability of the referee hereby provided for, or for any misconduct in him, or other good cause to such judge appearing, shall appoint such other properly qualified person in his stead as he shall deem proper, who shall proceed without delay to perform all the duties of his office, as herein pointed out, which shall remain unperformed by his predecessor in office.

Suits must be brought in four years; injunctions in what cases; what districts; commissioner's duty.

SEC. 2434. Nothing in this act or any decree rendered under the provisions thereof shall prevent any person, association, or corporation from bringing and maintaining any suit or action whatsoever hitherto allowed in any court having jurisdiction to determine any claim of priority of right of water by appropriation thereof for irrigation or other purposes, at any time within four years after the rendering of a final decree under this act in the water district in which such rights may be claimed, save that no writ of injunction shall issue in any case restraining the use of water for irrigation in any water district wherein such final decree shall have been rendered which shall affect the distribution or use of water in any manner adversely to the rights determined and established by and under such decree; but injunctions may issue to restrain the use of water in such district not affected by such decree, and restrain violations of any right thereby established; and the water commissioner of every district where such decree shall have been rendered shall continue to distribute water according to the rights of priority determined by such decree, notwithstanding any suits concerning water rights in such district; until any suits between parties the priorities between them may be otherwise determined, and such water commissioner have official notice by order of the court or judge determining such priorities, which notice shall be in such form and so given as the said judge shall order.

After four years suit barred.

SEC. 2435. After the lapse of four years from the time of rendering a final decree in any water district, all parties whose interests are thereby affected shall be deemed and held to have acquiesced in the same, except in case of suits before them brought; and thereafter all persons shall be forever barred from setting up any claim of priority of rights to water for irrigation in such water district adverse or contrary to the effect of such decree.

Sheriff not serve writ outside his county.

SEC. 2438. Nothing herein contained shall be construed to authorize any sheriff to serve any writ outside of the limits of his own county, or give effect to any record by way of notice or otherwise in any county other than that in which it belongs.

Fees of district clerk; how audited; paid.

SEC. 2439. The fees of the clerk of the district court for a service rendered under this act shall be paid by the counties interested, in the same manner as the fees of the water commissioners, upon said clerk rendering his account, certified by the district judge to the boards of county commissioners by the county or counties embracing the water district in case of which the service shall have been rendered.

State engineer; governor to appoint a State engineer; office; salary; oath; bond.

SEC. 2458. The governor shall appoint a State engineer, who shall hold his office for the term of two years, or until his successor shall be appointed and qualified. The governor may at any time, for cause shown, remove said State engineer. The said State engineer shall have his office at the State capitol, in suitable rooms, to be provided for him by the secretary of state, who shall furnish him with suitable furniture, postage, and such proper and necessary stationery, books, and instruments as are required to best enable him to discharge the duties of his office. He shall be paid a salary of three thousand dollars per annum, payable monthly by the State treasurer, on warrants drawn by the State auditor. The said State engineer shall, before entering on the discharge of his duties, take and subscribe to an oath, before the judge of a State court of record, to faithfully perform the duties of his office, and file said oath with the secretary of state, together with his official bond, in the penal sum of ten thousand dollars, said bond to be signed by sureties approved by the secretary of state and conditioned upon the faithful discharge of the duties of his office, and for delivering to his successor or other officer authorized by the governor to receive the same all moneys, books, instruments, and other property belonging to the State then in his possession or under his control, or with which he may be legally chargeable as such State engineer.

Engineer control waters, make measurements, collect data.

SEC. 2459. The State engineer shall have general supervising control over the public waters of the State. He shall make or cause to be made careful measurements of the flow of the public streams of the State from which water is diverted for any purpose and compute the discharge of the same. He shall also collect all necessary data and information regarding the location, size, cost, and capacity of dams and reservoirs hereafter to be constructed, and like data regarding the feasibility and economical construction of reservoirs on eligible sites, of which he may obtain information, and the useful purpose to which the water from the same may be put. He shall also collect all data and information regarding the snowfall in the mountains each season, for the purpose of predicting the probable flow of water in the streams of the State, and publish the same.

State engineer to have general charge of work; require reports.

SEC. 2461. The State engineer shall have general charge over the work of the division water superintendents and district water commissioners, and shall furnish them with all data and information necessary for the proper and intelligent discharge of the duties of their offices, and shall require them to report to him at suitable times their official actions, and require of them annual statements on blanks to be furnished by him of the amount of water diverted from the public streams in their respective divisions and districts, and such other statistics as, in the judgment of the State engineer will be of benefit to the State.

Appoint a deputy to measure.

SEC. 2462. The State engineer shall, on request of any party interested, and on payment of his per diem charges and reasonable expenses, appoint a deputy to measure, compute, and ascertain all necessary data of any canal, dam, reservoir, or other construction, as required or as may be desired to establish court decrees, or for filing statements in compliance with law in the county clerk's records.

Perform all duties imposed upon him; expenses.

SEC. 2463. The State engineer shall, without any extra pay or compensation beyond the salary provided in section one of this act, perform all duties imposed upon him by law, and shall, when called upon by the governor, give his counsel and services without extra pay or compensation to any State department or institution: *Provided, however*, That he shall be allowed all actual traveling and other necessary expenses, and the actual cost of preparing necessary maps and drawings, which actual expenses shall be paid by the department or institution requiring his services.

Require owners of ditches to construct and maintain a measuring weir.

SEC. 2466. For the more accurate and convenient measurement of any water appropriated pursuant to any judgment or decree rendered by any court establishing the claims of priority of any ditch, canal, or reservoir, the owners thereof may be required by the State engineer to construct and maintain, under the supervision of the State engineer, a measuring weir or other device for measuring the flow of the water at the head of such ditch, canal, or reservoir, or as near thereto as practicable. The State engineer shall compute and arrange in tabular form the amount of water that

will pass such weir or measuring device at the different stages thereof, and he shall furnish a copy of a statement thereof to any water superintendents or commissioners having control of such ditch, canal, or reservoir.

Unit of measurement. SEC. 2467. The State engineer shall use in all his calculations, measurements, records, and reports the cubic foot per second as the unit of measurement of flowing water and the cubic foot as the unit of measurement of volume.

Water commissioners; number; how appointed; bonds; term of office. SEC. 2381. There shall be one water commissioner for each of the above-named districts and for each district hereafter formed, who shall be appointed by the governor, to be selected by him from persons recommended to him by the several boards of county commissioners of the counties into which water districts may extend; and the water commissioner so appointed shall, before entering upon his duties, give a good and sufficient bond for the faithful discharge of his duties, with not less than three sureties, in a sum not less than one thousand nor more than five thousand dollars, the amount of said bond to be fixed by the county commissioners and approved by the governor and State engineer. The commissioner so appointed shall hold his office until his successor is appointed and qualified: *Provided*, *however*, That if such water district shall be embraced in more than one county, and the several counties in which such water district is situated disagree as to the amount of the bond as herein required of water commissioners, then and in that event the governor shall fix the amount thereof, with the same effect as though fixed by the county commissioners.

Duty of water commissioners; open and shut head gates. SEC. 2384. It shall be the duty of said water commissioners to divide the water in the natural stream or streams of their district among the several ditches taking water from the same, according to the prior rights of each, respectively, in whole or in part to shut and fasten, or cause to be shut and fastened by order given to any sworn assistant, sheriff, or constable of the county in which the head of such ditch is situated, the head gates of any ditch or ditches heading in any of the natural streams of the district, which, in a time of scarcity of water, shall not be entitled to water by reason of the priority of the rights of others below them on the same stream.

Water for domestic purposes. SEC. 1. Water claimed and appropriated for domestic purposes shall not be employed or used for irrigation or for application to lands or plants in any manner to any extent whatever: *Provided*, That the provisions of this section shall not prohibit any citizens or town or corporation organized solely for the purpose of supplying water to the inhabitants of such city or town from supplying water thereto for sprinkling streets and extinguishing fires, or for household purposes.

SEC. 2. Any person claiming the right to divert water for domestic purposes from any natural stream, who shall apply or knowingly permit the water so diverted to be applied for other than domestic purposes, to the injury of any other person entitled to use such water for irrigation, shall be deemed guilty of a misdemeanor, and upon conviction shall pay a fine of not less than fifty dollars and not exceeding two hundred dollars, in the discretion of the court wherein conviction is had. Each day of such improper application of water obtained in the manner aforesaid shall be deemed a separate offense. Justices of the peace in their several precincts shall have jurisdiction of the aforesaid offense, subject to the right of appeal as in cases of assault and battery.

Irrigation; conveyance of water rights. SEC. 1. In the conveyance of water rights hereafter made in this State, in all cases except where the ownership of stock in ditch companies or other companies constitute the ownership of a water right, the same formalities shall be observed and complied with as in the conveyance of real estate.

Approved April 7, 1893.

Irrigation; flow of water in ditches. SEC. 1. That section one of an act entitled "An act regulating the distribution of water, the superintendence of canals or ditches used for the purposes of irrigation, and providing a penalty for the violation thereof," approved March 19, 1887, be and the same is amended to read as follows:

SEC. 1. Every person or company owning or controlling any canal or ditch used for the purposes of irrigation and carrying water for pay shall, when demanded by the users during the time from April 1 to November 1, in each year, keep a flow of water therein, so far as may be reasonably practicable for the purpose of

irrigation, sufficient to meet the requirements of all such persons as are properly entitled to the use of water therefrom, to the extent, if necessary, to which such persons may be entitled to water, and no more: *Provided, however*, That whenever the rivers or public streams or sources from which the water is obtained are not sufficiently free from ice, or the volume of water therein is too low and inadequate for that purpose, then such canal or ditch shall be kept with as full a flow of water therein as may be practicable, subject, however, to the rights of priorities from the streams or other sources, as provided by law, and the necessity of cleaning, repairing, and maintaining the same in good condition.

Approved March 25, 1893.

WATER-RIGHT FORMS USED IN COLORADO.

No. 1.

Form of statement of claim for priority.

STATE OF COLORADO, *County of* ——— *ss:*

In the district court.

In the matter of the adjudication of priorities of water rights in water district No. —.

The undersigned hereby makes statement of claim in the above-entitled matter for the purpose of securing the benefits of the provisions of the law of the State of Colorado in relation to the adjudication of priorities of water rights, and states:

First. That he is the owner of the ditch (canal or reservoir) hereinafter named and described, and situated in said water district No. —; that his full name is ——— ———, and his post-office address is ———.

Second. The name of said ditch (canal or reservoir) is the ———.

Third. The head gate of said ditch (canal or feeder for said reservoir) is located on the ——— bank of ———, from which natural stream said ditch derives and diverts its supply of water, at a point whence the —— corner of section —, T. —, R. —, bears —— feet.

Fourth. From said head gate said ditch runs in a general ——— direction a distance of —— feet, thence (etc., describing the general course of the ditch or feeder).

Fifth. The length of said ditch is ——; its width is —— feet at the bottom and —— feet at high-water line; the depth of water carried by said ditch is —— feet; its grade is —— feet per mile.

Sixth. The carrying capacity of said ditch (or feeder) is —— cubic feet per second of time. (The capacity of said reservoir is —— cubic feet when filled to high-water mark.)

Seventh. The amount of water claimed by appropriation under and by means of the construction of said ditch is —— cubic feet per second of time. (The amount of water claimed under and by means of the construction of said reservoir is —— cubic feet.)

Eighth. Work was commenced on said ditch (canal or reservoir) on the —— day of ———, A. D. 18—, from which time said appropriation of water is claimed to date.

Ninth. The number of acres of land lying under and along said ditch (canal or reservoir) and being irrigated by water therefrom is ——.

Tenth. The size of said ditch (canal or reservoir) as enlarged (and extended) is as follows: Its length is ——; its width is —— feet at the bottom, and —— feet at high-water line; its depth of water is —— feet.

Eleventh. The increased capacity of said ditch (canal) arising from such enlargement is —— cubic feet per second of time. (The increased capacity of said reservoir arising from such enlargement is —— cubic feet.)

Twelfth. Work was commenced on said enlargement on the —— day of ———, A.D. 189—, from which time the additional appropriation of water by means of such enlargement is claimed to date.

Thirteenth. The amount of water claimed by appropriation under and by means of such enlargement of said ditch (canal) is —— cubic feet per second of time. (The amount of water claimed by appropriation under and by means of such extension of said reservoir is —— cubic feet.)

Fourteenth. The number of acres of land lying under and along said ditch (canal or reservoir) as enlarged and irrigated by water therefrom, is ——.

Witness —— hand— and seal— this —— day of ——, A. D. 18—.

—— ——. [SEAL.]
—— ——. [SEAL.]

STATE OF COLORADO, *County of* —— *ss:*

—— ——, being first duly sworn, on his oath says that he has read the foregoing, and that the matters and things set forth in such statement are true of his own personal knowledge.

—— ——.

Subscribed and sworn to before me this —— day of ——, A. D. 189—.

—— ——.

No. 2.

Form for map and statement.

A map, showing the point of location of the head gate, the route of the ditch or canal, the high-water line of the reservoir, the route of the feeder to and the ditches or canals from such reservoirs; the legal subdivisions of the lands upon which such structures are or are to be built, the names of the owners of such lands as far as the same are of record in the office of the county clerk of the county in which the same are situated; the courses, distances, and corners being given by reference to legal subdivisions on surveyed lands, or to natural objects if on unsurveyed lands; of a ditch (canal or feeder for a ditch or reservoir) for irrigation; being constructed (or about to be constructed or enlarged) by —— of ——.

(Here insert map, with particulars as above set forth.)

STATE OF COLORADO, *County of* ——, *ss:*

Water division No. —, district No. —.

The undersigned hereby makes statement of claim for priority in the use of water by appropriation, for the purpose of irrigation, and attaches the said statement to the foregoing map for the purpose of securing the benefits of the law of the State of Colorado in relation to such priority of water rights, and states:

(Here make statements as in form for adjudication of priorities, which see.)

STATE OF COLORADO, *County of* ——, *ss:*

—— ——, being first duly sworn, on his oath says that he has examined the above map and read the foregoing statement thereto attached, and that the matters and things shown on said map and set forth in said statement are true of his own personal knowledge.

—— ——.

Subscribed and sworn to before me this —— day of ——, A. D. 189—.

—— ——.

No. 3.

Form of petition for adjudication of priority.

STATE OF COLORADO, *County of* ——, *ss:*

In the district court.

In the matter of the application of —— —— and —— —— for the adjudication of the priorities of right to the use of water for irrigation purposes in water district No. — in said State of Colorado.

To the honorable district court of the —— judicial district of the State of Colorado within and for the county of ——, and to the honorable —— ——, judge of said court:

Your petitioners respectfully represent that they are the owners, respectively, of the —— and —— ditches (or reservoirs) located in said water district, taking

and using water from ——, and the tributaries thereof, in said water district, for irrigation purposes in the cultivation of lands adjacent to and under said ditches along the line thereof: that the petitioners herein are interested, as such owners aforesaid, in the settlement and adjudication of the priorities of right to the use of the waters of said stream, and the tributaries thereof, for irrigation purposes, between the several ditches, canals, and reservoirs, and owners of water rights in said water district No. —.

Wherefore your petitioners pray that your honor will proceed to an adjudication of the priorities of rights to the use of water for irrigation purposes between the several ditches, canals, and owners of water rights in said district No. — in said State, under the provisions of the constitution and the laws of the said State of Colorado in that behalf provided.

—— ——.

[NOTE.—It is customary to have the petition verified, although the statute does not seem to require it. The verification may be in the following form:]

STATE OF COLORADO, *County of* ——, *ss:*

I, —— ——, one of the petitioners, whose name is subscribed to the foregoing petition, do solemnly swear that I believe the matters and things set forth and stated in said petition are true in substance and in fact.

—— ——.

Subscribed and sworn to before me this —— day of ——, A. D. 18—.

—— ——.

No. 4.

Form for order for adjudication and appointment of referee.

In the district court.

In the matter of the application of —— —— and —— —— for the adjudication of the priorities of right to the use of water for irrigation purposes in water district No. — in said State of Colorado.

On this —— day of ——, A. D. 189—, the same being one of the judicial days of the ——, A. D. 189—, term of said district court (or before the Hon. —— ——, judge of said court, in vacation, at his chambers in the city of ——, in —— County, in the State of Colorado), come the above-named petitioners, and present their petition praying for an adjudication of the rights of petitioners and all other owners of or persons interested in ditches, canals, reservoirs, or water rights therein, taking water from the natural stream known as ——, and the tributaries thereof, in water district No. — in said State of Colorado.

And the said petition being read and considered by the court (or judge), it is hereby ordered that the same be filed in the office of the clerk of the district court in said county of ——, in the State of Colorado.

And it being deemed by the (judge of) said court impracticable to hear the evidence touching the rights of petitioners and others in this behalf in open court, it is further ordered that —— ——, esq., of the county of —— and State of Colorado (he being, in the opinion of the court (or judge), a discreet and qualified person), be, and he is hereby, appointed referee of the court in said matter, to whom is referred the said petition and all statements of claims to the use of water for irrigation from the natural streams of said water district heretofore filed, or that may hereafter be filed, in said court or in this proceeding.

Said referee shall take all evidence in the matter of said petition and the several priorities of right to water for irrigation purposes in said water district offered by parties who have filed or shall file their statements of claims, as required by law, and shall consider the same, and also any other evidence and testimony, if any there be, heretofore taken in said water district in any like proceeding, and shall make an abstract of said evidence and his findings upon the same, and draft a decree thereon, and report the same to this court; and generally said referee shall have all the powers and perform all the duties required of a referee of said court by the laws of the State of Colorado regulating the matter of the adjudication and determination of water rights and defining the duties and powers of referees appointed by courts of record: that before entering upon the discharge of his duties as such referee, and within ten days from the date of this order, the said referee shall file, in the office of the clerk of the district court for the county of ——, his written acceptance of this appointment and his oath of office as such referee.

No. 5.

Form of notice by referee.

In the matter of the adjudication of the priorities of water rights in water district No. —:

Whereas by an order (of the judge) of the district court of the ——— judicial district in the State of Colorado in and for the county of ———, the undersigned was appointed referee in the above matter, of which order the following is a copy:

(Here insert copy of order.)

Now, therefore, I do hereby give notice to all persons, associations, and corporations interested as owners or consumers of water in said water district No. — that I will, at the place and on the days hereinafter designated, attend for the purpose of hearing and taking evidence touching the priority of rights of the several ditches, canals, and reservoirs in said district, and will continue such hearing from day to day until all such evidence shall be taken, to wit:

At ———, at the office of ———, on the —— day of ———, A. D. 189—, at — o'clock —. m.

At ———, at the office of ———, on the —— day of ———, A. D. 189—, at — o'clock —. m.

And I do hereby notify all persons, corporations, and associations interested as owners or consumers of water in said district to attend by themselves, their agents or attorneys, at the time and places appointed herein, and then and there file a statement of claim in case no statement has been heretofore filed in the office of the clerk of the district court of ——— County aforesaid, such statement to be under oath and showing the ditch, canal, or reservoir in which the interest is claimed, together with the names of the owners thereof, and such other particulars as are prescribed by law; and all persons interested may then and there present proofs for or against any priority of right by appropriation sought to be shown by any party by or through any such ditch, canal, or reservoir, either as owner or consumer of water drawn therefrom.

——— ———,
Referee.

(Date.)

No. 6.

Form for order setting report of referee for hearing.

In the matter of the application of ——— ——— and ——— ——— for the adjudication of the priorities of the right to the use of water for irrigation purposes in water district No. — in said State of Colorado.

On this —— day of ———, A. D. 189—, the same being one of the judicial days of the ———, A. D. 189—, term of said district court, come again the above-named petitioners, by ——— ———, esq., their attorney; come also the following-named persons, corporations, and associations, who have severally filed claims herein for the right to use water for irrigation purposes in said water district No. —, to wit: ——— ———, by ——— ———, esq., his attorney; ——— ———, by ——— ———, esq., its attorney; comes also ——— ———, esq., referee heretofore appointed by the court herein to take the testimony and hear the evidence in this cause and make an abstract of such testimony and evidence and his findings upon the same, and to draft a decree thereon, and presents his report to the court of his action herein, together with his abstract of such testimony and evidence and his findings upon the same, and also with his draft of a decree herein.

And the said report, abstract, findings, and decree of said referee being read and considered by the court, it is hereby ordered that the same be filed in the office of the clerk of this court and set for hearing on the —— day of ———, A. D. 189—, to which time this cause is continued.

——— ———.

No. 7.

Form for decree adjudging priority.

In the matter of the application of ——— ——— and ——— ——— for the adjudication of the priorities of right to the use of water for irrigation purposes, in water district No. — in said State of Colorado.

And now on this —— day of ———, A. D. 189—, the same being one of the judicial days of the ———, A. D. 189—, term of said district court, come again the above-named petitioners by ——— ———, esq., their attorney; and the following-named persons, corporations, and associations, who have severally filed claims herein for the right to use water for irrigation purposes, in said water district No. —, to wit: (Here insert names of such persons, etc., together with the names of the attorneys representing them.)

And the said ——— ——— having filed herein his exceptions to the report, abstract, findings, and decree of ——— ———, referee, heretofore filed in this cause, which exceptions the court on consideration thereof doth overrule:

And it appearing to the court that no other exceptions to such report, abstract, findings, and decree have been filed herein:

And now this cause coming on to be heard upon the report of ——— ———, referee herein, and upon the evidence and testimony taken by said referee herein, together with his abstract of such evidence and testimony, and his findings thereon, and his draft of a decree submitted with his said report; and the court having heard the arguments of counsel herein and being fully advised in the premises, and upon consideration of such evidence, testimony, abstract, findings, draft of decree, and arguments of counsel, doth find:

That said referee has in every respect proceeded according to law and the judgment of the court appointing him as such referee in taking the testimony and hearing the evidence herein; and the actions and proceedings of said referee herein, together with his report, abstract, findings, and draft of decree, are hereby approved and confirmed by the court.

In regard to the ditch owned by ——— ———, whose post-office address is ———, which said ditch is named and known as the ——— ditch, the court finds:

That work was commenced on said ditch on the —— day of ———, A. D. 189—, from which time the appropriation of water therethrough should date; that work was prosecuted on said ditch with due diligence until its completion; that the nature of the work in constructing said ditch was rock cutting for a distance of —— from the head gate, and sand and gravel excavation for a further distance of ——; that the water is carried through flumes along the line thereof for a distance of ——; that the head gate of said ditch is on the —— bank of ——, from which stream said ditch derives and diverts its water, at a point whence the —— corner of Section ——, T. ——, R. ——, bears —— feet; that from said head gate said ditch runs in a general —— direction for a distance of ——, thence (etc., describing the course of the ditch in its general course); that the size and carrying capacity of said ditch as originally constructed was as follows: The length of said ditch was ——, its width at the bottom was —— feet; its width at high-water line was — feet, the depth of water carried by said ditch was — feet, its grade was — feet per mile, its carrying capacity was —— cubic feet per second of time;[1] that the size and carrying capacity of said ditch has remained substantially the same from the date of its construction up to this time; that the number of acres of land lying under and along said ditch and irrigated by water therefrom is ——; and that the owner of said ditch and of the water appropriated therethrough is entitled to a priority in the use of —— cubic feet of water per second of time by virtue of such appropriations.

In regard to the canal owned by the ——— Company, whose post-office address is ———, which said canal is named and known as the ——— canal, the court finds:

(Here insert particulars as in case of a ditch.)

In regard to the reservoir, feeder, and distributing ditches connected with such reservoir, owned by the ——— Association, whose post-office address is ———, which said reservoir, feeder, and distributing ditches are named and known as the ———, the court finds:

(Here describe commencement and location of work, its nature, location of head gate, from what stream and where water is diverted, the general course of

[1] The court further finds that said ditch was afterwards enlarged (and extended) by the owners thereof (find facts substantially as in case of the original ditch, as shown above); that the increased capacity of said ditch arising from such enlargement (and extension) is —— cubic feet per second of time; that the number of acres of land lying under and along said ditch as enlarged (and extended) and irrigated by water therefrom is ——; that the owner of said ditch and of the water appropriated therethrough is entitled to an additional priority in the use of —— cubic feet of water per second of time by virtue of such enlargement (and extension), and of the appropriation thereby made.

the feeder and distributing ditches, their length, width, depth, grade, and carrying capacity; the location, dimensions, and capacity of the reservoir; the number of acres of land lying under and along such reservoir, feeder, and distributing ditches, and irrigated by water therefrom, substantially as in case of a ditch.)

That the owners of said reservoir, feeder, and distributing ditches and the water so appropriated are entitled to the priority in the use of —— cubic feet of water per second of time, which they are entitled to divert during the irrigating season from such stream after all prior appropriators have been supplied with the amount of water they are entitled to by virtue of their appropriations; that the owners of said reservoir, feeder, and distributing ditches are also entitled to divert sufficient water from such stream during the nonirrigating season to fill their said reservoir to its capacity as hereinbefore found.

The court doth therefore order, adjudge, and decree that the owner of the ditch named and known as the —— ditch is entitled to a priority in the use of —— cubic feet of water per second of time from said natural stream known as ——, in said water district No. —; to date from the —— day of ———, A. D. 189—; that said ditch shall be numbered as ditch number one, and said appropriation therethrough shall be numbered as appropriation number one, in said water district No. —; that the owner of said ditch number one is entitled to an additional priority in the use of —— cubic feet per second of time from said stream, to date from the —— day of ———, A. D. 18—, on account of such enlargement (and extension) of said ditch and appropriation of water therethrough as aforesaid; that said additional appropriation shall be numbered as appropriation number three in said water district No. —.

That the owners of the canal named and known as —— are entitled to a priority in the use of —— cubic feet of water per second of time from said stream known as —— in said water district No. —, to date from the —— day of ———, A. D. 18—; that said canal shall be numbered as canal number two, and the appropriation therethrough as aforesaid shall be numbered as appropriation number two in said water district No. —.

That the owners of the reservoir named, known as ———, are entitled to a priority in the use of —— cubic feet of water per second of time, which they are entitled to divert from said stream during the irrigating season, provided the prior appropriations numbered one and two have been first supplied with the amount of water such appropriations are entitled to as aforesaid. The owners of said reservoir are also entitled to divert sufficient water from said stream during the nonirrigating season to fill said reservoir to its capacity of —— cubic feet, as heretofore found; that said reservoir shall be numbered as reservoir number one, said distributing ditch as ditch number three, and the appropriation therethrough as appropriation number four in said water district No. —.

The court doth further order, adjudge, and decree that each appropriation as aforesaid shall be entitled to the number of cubic feet of water per second of time from said stream in the order as the same are numbered as aforesaid, beginning at the lowest number or number one; and that each reservoir as aforesaid shall be entitled to the number of cubic feet of water from said stream up to its capacity as aforesaid, to be taken during the nonirrigating season from said stream in the order in which reservoirs are numbered as aforesaid, beginning with the lowest number of such reservoirs. In case all the water is not used during the irrigating season by prior appropriations, then said reservoirs are to be allowed to use such unused water from said stream as may be needed to fill the said reservoirs in the same order as aforesaid.

The court doth further order that each and every party interested in or claiming any ditch, canal, or reservoir as aforesaid, or any interest therein or in the water appropriated as aforesaid, shall receive from the clerk of this court, on payment of a fee of ———, which amount is adjudged by the court to be a reasonable fee, a certificate under the seal of the court showing the date or dates and the amount or amounts of such appropriations adjudged in favor of such ditch, canal, or reservoir, under and by virtue of the construction, extension, and enlargement thereof, severally as aforesaid, together with the number of said ditch, canal, or reservoir, and also of each appropriation or priority to which the same may be entitled by reason of such construction, enlargement, or extension.

No. 8.

Form of petition to fix rates.

STATE OF COLORADO, *County of* ——, *ss:*

Before the board of county commissioners.

In the matter of the application of —— and ——, parties interested in procuring water for irrigation purposes from the —— Canal and Reservoir Company.

To the honorable board of county commissioners of —— County, in the State of Colorado:

Your petitioners respectfully represent that they are the owners of the following described tracts and parcels of land lying in said county, to wit:

(Here describe lands of each petitioner.)

That such lands are farming and orchard lands which were originally of a wholly arid nature, on which crops could not be raised without artificial irrigation, but which have been reclaimed and brought into a state of cultivation by means of water which has been furnished petitioners by the —— Canal and Reservoir Company.

Your petitioners show that they are wholly dependent on the water furnished them by said —— Canal and Reservoir Company in irrigating and cultivating their said land, and have no other source from which they can secure water for such purposes.

Your petitioners show that said ditch and reservoir company has been charging your petitioner for such water at the rate of ——, which rate your petitioners believe to be unreasonable, unjust, and exorbitant; and although your petitioners have frequently applied to the proper officers of said company to have said rate reduced to a reasonable and just amount, yet said company has at all times refused and still does refuse to so reduce such rate.

Your petitioners aver that a reasonable and just rate of charge for such water would not be over ——, which amount your petitioners are now and have been at all times ready and willing to pay said company.

Your petitioners further show that the ditches, canals, and reservoirs of said —— Canal and Reservoir Company lie in great part within the boundaries of said county of —— and the remainder thereof lie in the county of ——, in said State of Colorado.

Your petitioners therefore pray that your honorable board will proceed to fix a just and reasonable rate for such company to charge your petitioners for such water, as provided by the law of the State of Colorado in such matters.

—— ——.
—— ——.

STATE OF COLORADO, *County of* ——, *ss:*

—— and —— ——, being each duly sworn on their several oaths, say that they have read the foregoing petition; that they are the same persons whose names are subscribed to said petition, and that the matters and things in said petition charged and stated are true of their own personal knowledge.

Subscribed and sworn to before me this —— day of ——, A. D. 189—.

—— ——.

STATE OF COLORADO, *County of* ——, *ss:*

—— ——, being duly sworn, on his oath says that he is a resident of said county and has been for —— years last past; that he is well acquainted with the lands of —— and of ——, as described in the foregoing petition, and also with the ditches, canals, and reservoirs of the said —— Canal and Reservoir Company in said counties of —— and ——; affiant is also acquainted with the rates of charges for furnishing water for irrigating purposes in said counties of —— and ——; affiant has read the foregoing petition, and verily believes the matters and things therein charged and stated are true, and that the rate of —— charged by said company for furnishing water, as therein stated, is unreasonable and unjust to said petitioners.

—— ——.

Subscribed and sworn to before me this —— day of ——, A. D. 189—.

—— ——.

(Add other affidavits if desired.)

No. 9.

Form of order setting petition down for hearing.

STATE OF COLORADO, *County of* ——, *ss:*

Before the board of county commissioners.

In the matter of the application of —— and ——, parties interested in procuring water for irrigation purposes from the —— Canal and Reservoir Company.

On this —— day of ——, A. D. 189—, the same being one of the ——, A. D. 189—, sessions of said board of county commissioners, come before the said board —— and —— and present their petition, and affidavit thereto attached, representing and showing to the board that the —— Canal and Reservoir Company are charging said petitioners unjust and unreasonable rates for water furnished for irrigation purposes to said petitioners by said company, and that said company refuses to reduce such rates to a just and reasonable amount; and the board having examined said petition and affidavits, and having heard the testimony of other witnesses in regard thereto, find from said petition, affidavits, and testimony that the facts sworn to show such application to be and to have been made in good faith, and that there is reasonable ground to believe that unjust rates are or are about to be charged by said company for furnishing water for irrigation purposes as aforesaid.

The board doth therefore order that said petition be set for hearing on the —— day of ——, A. D. 189—, when all parties interested in said company or the ditches, canals, or reservoirs thereof, or in procuring water therefrom, will be heard by the board in regard thereto; to which time this matter is hereby continued.

WATER LAWS OF KANSAS.

CHAPTER 78.—GENERAL STATUTES OF KANSAS.

Water may be appropriated. SEC. 1. The right to the use of running water flowing in a river or stream in this State for the purposes of irrigation may be acquired by appropriation. As between appropriators, the one first in time is the first in right.

Place of diversion may be changed. SEC. 2. Any person, company, or corporation entitled to the use of water may change the place of diversion if others are not injured by such change, and may extend the canal, ditch, flume, or aqueduct by which the diversion is made to places beyond that to where the first use was made.

Notice required. SEC. 3. Any person, company, or corporation desiring hereafter to appropriate water must post a notice in writing at a conspicuous place at the point of diversion, stating therein, first, that such person, company, or corporation claims the water there flowing to the extent of —— (giving the number of) inches, measured under a four-inch pressure, and describing and defining as accurately as may be the place of diversion; second, the means by which such person, company, or corporation intends to divert it, and the size of the canal, ditch, or flume, or aqueduct in which he intends to divert it. A copy of such notice must, within ten days after it is posted at the place of diversion, be also posted in a conspicuous place in the office of the county clerk of the county in which such place of diversion is situated, and be recorded by the county clerk in a book to be kept for that purpose.

NOTE.—The notices required by this section are, as regards the counties lying west of the ninety-ninth degree of west longitude, required by section one hundred and seven of chapter seventy-nine to be filed with and recorded by the register of deeds, and the notices previously filed with and recorded by the county clerk are by such clerk to be turned over to the register of deeds of his county for record by such register.

SEC. 107. Upon the passage and taking effect of this act the county clerk of any county wherein has been provided a record of appropriation of water, and proof of the posting of notices thereof, as required by section five of chapter one hundred and fifteen of the laws of 1886 (section five of chapter seventy-eight of this work), shall forthwith turn over the same to the register of deeds of said county; and such notices and proof of posting thereof shall be recorded by the register of deeds of any such county, instead of by the county clerk thereof; and hereafter any person, company, or corporation posting any notice of the appropriation of water from any source shall specify the amount appropriated in cubic feet per second, instead of inches, measured under a four-inch pressure, as heretofore required.

Work must be prosecuted with diligence. SEC. 4. Within sixty days after the notice is posted the claimant must commence the excavation or construction of the works in which such claimant intends to divert the water, and must prosecute the work diligently and uninterruptedly to completion, unless interrupted by stress of weather. By completion is meant conducting the water to the place of its intended use.[1] By a compliance with the above rules the claimant's right to the use of the water relates back to the time the notice was posted. A failure to comply with such rules shall deprive the claimant of the right to the use of the water as against a subsequent claimant who complies therewith.

Commissioner of irrigation. SEC. 36. The investigation of the two sciences of forestry and irrigation shall be continued under one commissioner, whose official title shall be "commissioner of forestry and irrigation," who shall be appointed by the governor, by and with the advice and con-

[1] This is modified by section 2, chapter 79.

sent of the senate, and who shall hold his office for the period of four years, subject only to removal for cause. Said commissioner shall be a person who has made a thorough study of both sciences and is versed in practical forestry and irrigation. The said commissioner shall have charge of the work contemplated by this act, in addition to that mentioned in the forestry law.

CHAPTER 79.—STORAGE OF WATER AND IRRIGATION.

[West of the ninety-ninth degree of west longitude.]

Water may be appropriated.

SEC. 1. In all that portion of the State of Kansas situated west of the ninety-ninth meridian all natural waters, whether standing or running and whether surface or subterranean, shall be devoted, first, to purposes of irrigation in aid of agriculture, subject to ordinary domestic uses; and, secondly, to other industrial purposes, and may be diverted from natural beds, basins, or channels for such purposes and uses: *Provided*, That no such diversion shall interfere with, diminish, or divest any prior vested right of appropriation for the same or a higher purpose than that for which such diversion is sought to be made without the due legal condemnation of and compensation for the same; and natural lakes and ponds of surface water having no outlet shall be deemed parcel of the lands whereon the same may be situate, and only the proprietors of such lands shall be entitled to draw off or appropriate the same.

Right limited to the volume applied to beneficial use.

SEC. 2. The appropriation of water hereafter shall in every case be deemed and be taken to be accomplished and effectual only as to so much water as shall have been actually applied to beneficial uses within a reasonable time after the commencement of the works by means of which such appropriation is intended to be made, or afterward where no appropriation has in the meantime been initiated by others, together with the reasonable amount necessary to supply losses by waste, seepage, and evaporation. All the residue of the water within the capacity of the canal or other works shall be deemed to be derelict and liable to appropriation by any subsequent appropriator.

Natural streams may be used.

SEC. 3. Any person may conduct water into and along any of the natural streams or channels of the State, and may withdraw all such waters so by him turned into such channel at any point desired, without regard to prior appropriations of water from said stream, due allowance being made for evaporation and seepage.

Place of diversion may be changed.

SEC. 4. In case the channel of any natural stream shall have become so cut down, lowered, turned aside, or otherwise changed from any cause as to prevent any ditch or conduit for the diversion of water from receiving the proper inflow of water to which it may be entitled, the proprietors of such ditch or conduit may, within a reasonable time after such change, extend such ditch or conduit to such stream, or along the course thereof, or may erect a dam or embankment for turning water into the same; and the right of such proprietors to take water from such stream through such ditch or conduit as so extended, to the same amount and during the same period as prior to such change, shall be of the same priority as before such extension: *Provided*, That no such extension shall be allowed in such manner as to interfere with the operation or enjoyment of any other ditch, conduit, or other works for the diversion, conveyance, or storage of water.

Subterranean waters may be appropriated.

SEC. 5. Waters flowing in well-defined subterranean channels and courses, or flowing or standing in subterranean sheets or lakes, shall be subject to appropriation with the same effect as the water of superficial channels; and no person shall be allowed by drains, ditches, fountains, subterranean galleries, or other works to collect and divert percolating waters manifestly supplying such subterranean supplies, to the prejudice of any prior appropriator thereof: *Provided*, That nothing in this section contained shall be so construed as to render any person liable in damages for the diversion or obstruction of the flow of subterranean waters by lawfully excavating for cellars, or for mining, quarrying, or carrying on like works on his own lands, nor for excavating drains for draining and improving his own lands, nor so as to prohibit the proprietor of any lands from sinking wells therein, and thereby collecting the waters percolating through lands, and by means of pumps, buckets, and other appliances withdrawing the same for beneficial uses on his own land: *And provided further*, That any appropriation and diversion of subterranean waters which simply lower a water level without in *fact exhausting* or seriously diminishing the actual and needful supply of any

prior appropriator for domestic or other beneficial uses shall not be considered an unlawful appropriation or diversion thereof.

SEC. 6. No person shall be permitted to take or appropriate the waters of any subterranean supply which naturally discharge into any superficial stream, to the prejudice of any prior appropriator of the water of such superficial channel.

Rights of users to artesian waters.

SEC. 7. Every person complying with the provisions of this act, and applying the waters obtained by means of any artesian well to beneficial uses, shall be deemed to have appropriated such waters to the extent to which the same shall be so applied within a reasonable time after the commencement of the works, and such appropriation shall have effect as of the day of commencement of such works provided the same is prosecuted with reasonable diligence; otherwise, from the time of the application of the waters thereof to beneficial uses.

Rights depend on continuous use.

SEC. 8. Any prior right of appropriation shall exist and continue only by the exercise thereof in a lawful manner, and any failure of such appropriator continuously to apply such water to lawful and beneficial uses, without due and sufficient cause shown for such failure, shall be deemed an abandonment and surrender of such right.

Appropriations subject to eminent domain.

SEC. 9. Every vested right of prior appropriation or diversion of water for industrial uses shall be subject to the right of eminent domain, and may be condemned and compensated for, for public and beneficial uses, in the same manner and under the same restrictions and regulations as govern the condemnation of other private property.

SEC. 11. Any person may at any time take water from any natural stream or open ditch, conduit, or reservoir at any public road crossing, or at any place upon his own lands, or upon the lands of others, by license of the proprietor thereof, or without such license where such lands are uninclosed and uncultivated, for filling barrels or other vessels for his domestic uses.

Right to store water.

SEC. 13. Any person entitled to the use of water for the irrigation of lands or other purposes whatsoever may, at any time while so entitled to the use thereof, collect and store the same up for use presently thereafter, and the failure to apply or use such waters during the period of such collection and storage shall not be deemed or taken to impair his right in that behalf.

When sale of right constitutes abandonment.

SEC. 14. Any person transferring, selling, leasing, assigning, or bargaining with reference to the transfer, sale, lease, or assignment of any water, or any right he may have acquired to the use thereof, and any person receiving any money or other valuable thing whatsoever in consideration of the prorating or rotating of water, or in consideration of his agreement to prorate or rotate water, shall be deemed and taken to have abandoned all right to the use or enjoyment of such water; provided, however, such abandonment shall not operate to the prejudice of the rights of any incumbrancer or equitable owner of the lands, mill, manufactory, or other works to which such water is appurtenant.

NOTE.—Section fifteen is similar to section nine.

Water shall be prorated in time of scarcity.

SEC. 28. It shall be the duty of the superintendent of every such ditch, conduit, or reservoir to measure the water therefrom through the outlets to those entitled thereto, and in time of scarcity to apportion the waters flowing in such ditch or conduit or collected in such reservoir among those entitled thereto ratably, and according to the amounts to which they are severally entitled. Where any such ditch, conduit, or reservoir hath, subsequent to the original construction been enlarged, the water diverted, collected, conveyed, or stored by means of such enlargement shall be distributed and apportioned in like manner. The several consumers of water under any lateral may at any time, by a vote of a majority thereof, appoint a superintendent to such lateral, who shall be charged with the distribution of the water allotted thereto by the superintendent of the ditch among those entitled to the use of water from such lateral. A meeting may at any time be called by not less than two of the consumers under such lateral, by notice in writing, specifying the time, place, and purpose thereof, for electing such superintendent, or removing him and appointing another. Such superintendent shall hold his office during the pleasure of the consumers of water from such lateral, or a majority of them, and shall receive only such salary or compensation as they may appoint.

When head gates may be closed.

SEC. 29. The waters of the several streams and sources of supply shall be distributed among the several canals, ditches, conduits, and other works so that the proprietors of each of said works, and those entitled to water therefrom shall, as nearly as may be and to the extent of their needs, at all times receive and enjoy the waters to which they are severally entitled; and whenever it shall appear that there is flowing into any such works water to which the proprietor of any other such works having a prior right is entitled and that such other works having priority of right, is not receiving the water necessary for the consumers of water therefrom and which ought to flow to the same, the head gate of such works having the excess, and being subsequent in right, shall be closed, or partly closed, so that a sufficient amount of water of such stream or source of supply may pass and flow to the said works having the priority of right to the amount to which the same shall be entitled; and if the proprietors of any such works having such excess and being subsequent in right shall fail or refuse to turn out such supply of water when requested by the party entitled to receive the same so to do, the head gate or waste gate of the works receiving such excess shall be so set and locked by the officer authorized by law to perform such duty as to permit a sufficient amount of said water to pass and flow to the party having the right to receive the same.

Records of artesian wells.

SEC. 30. Any person sinking or boring for an artesian well shall cause to be kept thereat a record of the work, setting forth the name and post-office address of the proprietor of such well, or of the person causing such well to be sunk or bored, the name of the contractor therefor, and the name of the person actually in charge of the work; the particular location thereof, specifying the particular forty acres and the part thereof whereon the same is situated; if in any city or town, the particular lot or block or other subdivision upon which or nearest to which the same is situate; the date of commencement of work in sinking or boring such well (which may be the commencement of the work of placing machinery therefor); all suspension of the work and the duration of such suspension; the time of completion of the work or final cessation thereof; the different strata passed through, and the depth at which each thereof shall be reached and passed as near as may be, showing also each flow of water obtained, and each vein of water or water-bearing strata passed through, and the depth thereof from the surface, numbering each flow or vein of water consecutively from the surface, and the height to which or the distance from the surface the water rises in such well after penetrating each separate flow or vein of water; and at the completion of the well, or at the cessation of work thereon, he shall, without first closing or shutting off the flow therefrom, cause to be ascertained the flow thereof, if a flowing well, in cubic feet per second or decimal fraction thereof; and within a period of thirty days next after completion of such well, or the cessation of work thereon, the proprietor thereof shall make, or cause to be made, and file in the office of the register of deeds of the county wherein the said well is situate a statement or certificate, verified by his affidavit, or the affidavit of the person in charge of the work, setting forth all the matters aforesaid, the particular vein or flow of water claimed to be appropriated by means of said well, and the total amount of water so claimed to be appropriated, in cubic feet per second or decimal fractions thereof, if such well be a flowing well (otherwise the distance from the surface at which the water customarily stands), what part or parts of such well is or are cased, and the interior diameter or diameters of such casing or casings.

Water-right filings on artesian wells.

SEC. 31. Every person who is the proprietor of or entitled to the waters of any artesian well heretofore sunk or bored shall, within ninety days after this act takes effect, make and cause to be filed in said office a like statement, setting forth all the foregoing matters so far as within his knowledge, and according to the best of his knowledge, information, and belief.

Artesian priorites.

SEC. 32. Any person owning or controlling any artesian well may record such certificate provided for in sections ten and eleven of this article (sections thirty and thirty-one of this chapter) in any county or counties in addition to the county wherein such well is situated; and such record shall be to all parties boring or sinking any artesian well in any such county notice of the priority of the appropriation of water claimed by the party recording such certificate, and the prior right of such appropriation may be enforced as against any and all parties in such county or counties having acquired or seeking to acquire any subsequent right of appropriation of such waters.

SEC. 44. The proprietors of two or more canals, ditches, reservoirs, or other works taking water from the same source of supply may, by a consent in writing of those entitled to the use of the water therefrom, agree in like manner for the rotation of the whole or any part of the water lawfully allotted from such stream or source of supply to such ditches, conduit, or other works in such way and manner and for such time as may be in such agreement specified; provided, however, that the rotation of the water to which the several consumers, parties to such agreement, are entitled shall not be conducted in such manner as to diminish the supply of water from any other ditch, conduit, or other works (to which such parties or any of them) may be entitled.

SEC. 45. Whenever any agreement shall be entered for the rotation of the water of any ditch, conduit, reservoir, or other works, or any lateral of such ditch or conduit, or any part of such water, among those entitled to the use of such water, such agreement, or one part or copy thereof, shall be delivered to the superintendent of the ditch, conduit, reservoir, or lateral, and be by him carefully preserved, and he shall cause the water to which the parties thereto may be entitled to be rotated and distributed conformably to the said agreement during the time mentioned therein for the continuance in force of such agreement.

When rotation may not be permitted.

SEC. 46. No agreement entered into between the proprietors of any two or more canals, ditches, conduits, reservoirs, or other works for the rotation of the water thereof in manner as hereinbefore provided shall be permitted to go into effect if it shall be manifestly injurious to the proprietors of other canals or other works, or the consumers of water therefrom; and if after experiment the execution of such agreement be found injurious to other persons, the further rotation of the waters pursuant to such agreement must be discontinued.

When agreement for rotation may be annulled.

SEC. 47. The proprietors of any canal or other works not party to such agreement, or any consumer of water therefrom, shall be entitled to make application to the judge of the district court in and for the county wherein said applicant shall reside, asking that such agreement be annulled. Reasonable notice of every such application shall be given to the proprietors of the canals and other works, parties to such agreement, and the district judge may require like notice to be given to all others in interest, by application as may by him be prescribed. The proprietors of any such canal or other works, or any consumer of water, or person entitled to the use of water from any such works, shall be heard, and the district judge shall make such order in the premises as right and justice may require; provided, however, that during the pendency of any such application the waters allotted to the canals, ditches, or other works, the proprietors whereof are parties to such agreement, shall be distributed and rotated conformably to such agreement.

When agreement for rotation may not be permitted.

SEC. 48. No agreement for the rotation of water shall in any manner impair or affect the rights of any prior incumbrancer of lands theretofore customarily irrigated by any part of the waters mentioned in such agreement, he not being a party to such agreement; nor shall such agreement, or the rotation of the waters pursuant thereto, in any manner affect or impair the rights or the priority of right of the parties thereto, or the persons using or entitled to use the waters referred to in such agreement, or any of them, as against other persons.

When agreement for rotation must be recorded.

SEC. 49. Whenever any such agreement for the rotation of water, either between or among several ditches, conduits, reservoirs, or other works, or among those entitled to the use of the waters of any ditch, conduit, reservoir, or other works, or any lateral therefrom or any part of such water, shall be for a space exceeding one season, the same shall be recorded in the office of the register of deeds of the county wherein is situate the head gate of such ditch or conduit, or wherein is situate such reservoir or the head of the lateral.

Appropriation of seepage waters.

SEC. 53. The proprietor of any lands which have become saturated by seepage waters flowing out of any ditch, canal, reservoir, or conduit shall be entitled to cut and open drains or trenches, or lay pipes or conduits for draining such lands and withdrawing the water therefrom, and conveying the same into any natural stream, arroyo, or water course; or may at his election convey such waters to other lands or places whatsoever, and apply the same to domestic, agricultural, manufacturing, or other purposes, in his pleasure.

Royalties for water furnished.

SEC. 81. It shall not be lawful for any person association, or corporation owning or controlling, or claiming to own or control, any ditch, canal, or *reservoir carrying* or storing, or designed for the carrying or storing, of water

taken from any natural stream, or other source of supply within this State, to be carried or stored and delivered for compensation, for irrigation, milling, sanitary or domestic purposes to persons not interested in such ownership or control, to demand, bargain for, accept, or receive from any person who may apply for water for any of the aforesaid purposes any money or other valuable thing whatsoever, or any promise or agreement therefor, directly or indirectly, as royalty, bonus, or premium, prerequisite or condition precedent to the right or privilege of applying or bargaining for or procuring such water; but such water shall be carried or stored and delivered according to the right of the person entitled to the enjoyment thereof, upon the payment or tender of the charges fixed by the county commissioners of the proper county, as is or may be provided by law. Any and all moneys and every valuable thing or consideration of whatsoever kind which shall be so as aforesaid demanded, charged, bargained for, accepted, received, or retained contrary to the provisions of this section, shall be deemed and held an additional and corrupt rate, charge, or consideration for the water intended to be furnished and delivered therefor, or because thereof, and wholly extortionate and illegal, and when paid or delivered or surrendered may be recovered back by the party or parties paying, delivering, or surrendering the same, from the party to whom or for whose use the same shall have been paid, delivered, or surrendered, together with all costs of suit, including reasonable fees of attorneys of plaintiff, by proper action in any court having jurisdiction.

Penalty for demanding royalty.

SEC. 82. Every person, association, or corporation owning or controlling, or claiming to own or control, any ditch, canal, or reservoir as is mentioned in the first section of this article (section eight of this chapter), any officer or agent of such association or corporation, who shall, after demand in writing made upon him for the supply or delivery of water for irrigation, manufacturing, milling, or domestic purposes, to be delivered from the ditch, canal, or reservoir owned, possessed, or controlled by him, and after tender of the lawful rates of compensation therefor in lawful money, demand, require, bargain for, accept, or retain from the party making such application any money or other thing of value, or any promise or contract or any valuable consideration whatever as such royalty, bonus, premium, prerequisite, or condition precedent, as is by the provisions of the first section of this article prohibited, shall be deemed guilty of a misdemeanor, and on conviction thereof shall be punished by a fine of not less than one hundred dollars nor more than five thousand dollars, or imprisonment for a term of not less than three months nor more than one year, or both such fine and imprisonment, in the discretion of the court.

District courts have jurisdiction in determining priorities.

SEC. 103. Exclusive jurisdiction for the ascertainment and settlement of the several rights and priorities of right of persons interested, either as carrier or consumer, in water at any time appropriated is hereby conferred upon the several district courts having jurisdiction within the limits prescribed by this act; and the judge of any such district court may, whenever necessity therefor shall arise, appoint a water bailiff, commissioning him under the seal of the court of the county wherein said judge shall at the time be, ordering and empowering such water bailiff to prevent the waste of water from any artesian well, or the unlawful use thereof, or from the artesian wells of any district by any person or persons, and to enforce priority of right of appropriation of such waters, or to demand and receive any key or keys to any head gate or head gates, waste gate or waste gates, or any other works in this act specified, and to safely keep the same so long as shall be necessary to carry out the orders of said court (returning the same thereafter to the owner or owners thereof or disposing of the same according to the order of the court), and to divide the waters of any source of supply according to the rights and priorities of the parties entitled to receive the same, and conformably to the order of said court, and to open or close any such head gate or waste gate, or fill any such canal or ditch as may be required to enforce the orders of such court under the provisions of this act respecting the distribution of water to the parties lawfully entitled to receive the same. Such water bailiff shall be by said order authorized and empowered to employ such assistance as may be necessary to discharge his duties, and shall receive a compensation of two dollars per day for each day actually and necessarily employed in executing the orders of said court, and all expenses necessarily incurred in the discharge of his duties, to be paid on the certificate of the district judge by the board of county commissioners of the county wherein such services were rendered and such expenses incurred, such service and expense being apportioned and certified by said district judge to the county or several counties concerned.

WATER LAWS OF MONTANA.

CONSTITUTIONAL PROVISIONS.

The use of all water now appropriated, or that may hereafter be appropriated, for sale, rental, distribution, or other beneficial use, and the right of way over the lands of others for all ditches, drains, flumes, canals, and aqueducts, necessarily used in connection therewith, as well as the sites for reservoirs necessary for collecting and storing the same, shall be held to be a public use.—Art. III, sec. 15.

STATUTORY ENACTMENTS.

All the Montana laws on the subject of irrigation are found in the civil code of the Revised Statutes.

Rights may be acquired by appropriation.

SEC. 1880. The right to the use of running water flowing in the rivers, streams, canyons, and ravines of this State may be acquired by appropriation.

Must be for some useful purpose.

SEC. 1881. The appropriation must be for some useful or beneficial purpose, and when the appropriator or his successor in interest abandons and ceases to use the water for such purpose the right ceases; but questions of abandonment shall be questions of fact, and shall be determined as other questions of fact.

Place of diversion and use may be changed.

SEC. 1882. The person entitled to the use of water may change the place of diversion, if others are not thereby injured, and may extend the ditch, flume, pipe, or aqueduct by which the diversion is made, to any place other than where the first use was made, and may use the water for other purposes than that for which it was originally appropriated.

May be turned into another stream.

SEC. 1883. The water appropriated may be turned into the channel of another stream and mingled with its waters, and then be reclaimed; but, in reclaiming it, water already appropriated by another must not be diminished in quantity or deteriorated in quality.

Surplus must be returned to the stream.

SEC. 1884. In all cases where, by virtue of prior appropriation, any person may have diverted all the water of any stream, or to such an extent that there shall not be an amount sufficient left therein for those having a subsequent right to the waters of such stream, and there shall at any time be a surplus of water so diverted, over and above what is actually used by the prior appropriator, such person shall be required to turn and to cause to flow back into the stream such surplus water, and upon failure so to do, within five days after demand being made upon him in writing by any person having a right to the use of such surplus water, the person so diverting the same shall be liable to the person aggrieved thereby in the sum of twenty-five dollars for each and every day such water shall be withheld after such notice, to be recovered by civil action by any person having a right to the use of such surplus water.

First in time first in right.

SEC. 1885. As between appropriators the one first in time is first in right.

Notice of appropriation.

SEC. 1886. Any person hereafter desiring to appropriate water must post a notice in writing in a conspicuous place at the point of intended diversions, stating therein:

1. The number of inches claimed, measured as hereinafter provided.
2. The purpose for which it is claimed, and place of intended use.
3. The means of diversion, with size of flume, ditch, pipe, or aqueduct by which he intends to divert it.
4. The date of appropriation.
5. The name of the appropriator:

Within twenty days after the date of appropriation the appropriator shall file with the county clerk of the county in which such appropriation is made a notice of appropriation, which, in addition to the facts required to be stated in the posted notice, as hereinbefore prescribed, shall contain the name of the stream from which the diversion is made, if such stream have a name, and if it have not, such a description of the stream as will identify it, and an accurate description of the point of diversion on such stream, with reference to some natural object or permanent monument. The notice shall be verified by the affidavit of the appropriator, or some one in his behalf, which affidavit must state that the matters and facts contained in the notice are true.

Work must be prosecuted with diligence.

SEC. 1887. Within forty days after posting such notice the appropriator must proceed to prosecute the excavation or construction of the work by which the water appropriated is to be diverted, and must prosecute the same with reasonable diligence to completion. If the ditch or flume, when constructed, is inadequate to convey the amount of water claimed in the notice aforesaid, the excess claimed above the capacity of the ditch or flume shall be subject to appropriation by any other person, in accordance with the provisions of this title.

Right to date from posting of notice.

SEC. 1888. A failure to comply with the provision of this title deprives the appropriator of the right to the use of water as against a subsequent claimant who complies therewith; but by complying with the provisions of this title the right to the use of the water shall relate back to the date of posting the notice.

Record with county clerk.

SEC. 1889. Persons who have heretofore acquired rights to the use of water shall, within six months after the publication of this title, file in the office of the county clerk of the county in which the water right is situated a declaration in writing, except notice be already given of record as required by this title, or a declaration in writing be already filed as required by this section, containing the same facts as required in the notice provided for record in section eighteen hundred and eighty-six of this title, and verified as required in said last-mentioned section, in cases of notice of appropriation of water; provided, that a failure to comply with the requirements of this section shall in no wise work a forfeiture of such heretofore acquired rights, or prevent any such claimant from establishing such rights in the courts.

Record prima facie evidence.

SEC. 1890. The record provided for in sections eighteen hundred and eighty-six and eighteen hundred and eighty-nine of this title, when duly made, shall be taken and received in all courts of this State as prima facie evidence of the statements therein contained.

Water right procedure in district court.

SEC. 1891. In any action hereafter commenced for the protection of rights acquired to water under the laws of this State, the plaintiff may make any or all persons who have diverted water from the same stream or source parties to such action, and the court may, in one judgment, settle the relative priorities and rights of all the parties to such action. When damages are claimed for the wrongful diversion of water in any such action, the same may be assessed and apportioned by the jury in their verdicts, and judgment thereon may be entered for or against one or more of several plaintiffs, or for or against one or more of several defendants, and may determine the ultimate rights of the parties between themselves.

In any action concerning joint water rights, of joint rights in water ditches, unless partition of the same is asked by parties to the action, the court shall hear and determine such controversy as if the same were several as well as joint.

Clerk must keep a record.

SEC. 1892. The county clerk must keep a well-bound book, in which he must record the notices and declarations provided for in this title, and he shall be entitled to have and receive the same fees as are now or hereafter may be allowed by law for recording instruments entitled to be recorded.

Manner of measuring water.

SEC. 1893. The measurement of water appropriated under this title shall be conducted in the following manner: A box or flume shall be constructed with a head gate placed so as to leave an opening of six inches between the bottom of the box or flume and lower edge of the head gate, with a slide to enter at one side of, and of sufficient width to close the opening left by the head gate, by means of which the dimensions of the opening are to be adjusted.

The box or flume shall be placed level, and so arranged that the stream in passing through the aperture is not obstructed by backwater, or an eddy, below the gate; but before entering the opening to be measured the stream shall be brought

to an eddy, and shall stand three inches on the head gate and above the top of the opening. The number of square inches contained in the opening shall be the measure of inches of water.

Sale of surplus. SEC. 1897. Any person having the right to use, sell, or dispose of water and engage in using, selling, or disposing of the same, who has a surplus of water not used or sold, or any person having a surplus of water and the right to sell and dispose of the same, is required, upon the payment or tender to the person entitled thereto an amount equal to the usual and customary rates per inch, to convey and deliver to the person such surplus of unsold water, or so much thereof for which said payment or tender shall have been made, and shall continue so to convey and deliver the same weekly, so long as said surplus of unused or unsold water exists and said payment or tender be made as aforesaid.

Purchaser of surplus must build channel to convey same. SEC. 1898. Any person desiring to avail himself of the provisions of the preceding section, must, at his own cost and expense, construct or dig the necessary flumes or ditches to receive and convey the surplus water so desired by him, and pay or tender to the person having the right to the use, sale, or disposal thereof an amount equal to the necessary cost and expense of tapping any gulch, stream, reservoir, ditch, flume, or aqueduct and putting in gates, gauges, or other proper and necessary appliances usual and customary in such cases, and until the same shall be so done, the delivery of the said surplus water shall not be required as provided in the preceding section.

May enforce rights to purchase surplus. SEC. 1899. Any person constructing the necessary ditches, aqueducts, or flumes, and making the payments or tenders hereinbefore provided, is entitled to the use of so much of the said surplus water as said ditches, flumes, or aqueducts have the capacity to carry, and for which payment or tender is made, and may institute and maintain any appropriate action at law or in equity for the enforcement of such right or recovery of damages arising from a failure to deliver or wrongful diversion of the same.

Purchaser of surplus may not resell the same. SEC. 1900. Nothing in the three preceding sections shall be so construed as to give the person acquiring the right to the use of water as therein provided the right to sell or dispose of the same after being so used by him, or prevent the original owner or proprietor from retaking, selling, and disposing of the same in the usual and customary manner, after it is so used as aforesaid.

WATER-RIGHT FORMS USED IN MONTANA.

Notice of water right.

STATE OF MONTANA, *County of* ———, *ss:*

To all whom these presents may concern:

Be it known, That ———, of ———, in said county and State, do hereby publish and declare, as a legal notice to all the world, ———:

I. That ——— ha— a legal right to the use, possession, and control of and claim ——— inches of the waters of ——— in said county and State, for irrigating and other purposes.

II. That the special purpose for which said water is intended to be used, and the place of intended use is ———.

III. That ——— have taken said water out of, and diverted it from said ——— by means of ———, which said ——— is — inches by — inches in size and carries or conducts ——— inches of water from said ———: said ——— taps and diverts the water from said stream at a point upon its ——— bank ———; thence running, or to run, to and upon said described land (and through said land, if ——— so desire, to any requisite point of final discharge).

IV. That ——— appropriated and took said water on the ——— day of ———, A. D. 189—, by means of said ———.

V. That the name— of the appropriator — of said water ———.

VI. That ——— also hereby claim said ditch and the right of way therefor, and for said water by it conveyed, or to be conveyed, from said point of appropriation to said land or point of final discharge, and also the right of location upon any lands of any dams, flumes, reservoirs, constructed, or to be constructed, by ——— in appropriating, and in using said water.

VII. That —— also claim the right to keep in repair and to enlarge said means of water appropriation at any time, and the right to dispose of the said right, water, ditch, or said appurtenances, in part or whole, at any time.

Claiming the same, all and singular, under any and all laws, national and State, and —— rulings and decisions thereunder, in the manner of water rights.

Together with all and singular the hereditaments and appurtenances thereunto belonging or appertaining, or to accrue to the same.

Witness —— hand at ——, Montana, this —— day of ——, 189—.

—— ——.

THE STATE OF MONTANA, *County of* ——, *ss:*

—— ——, having first been duly sworn, depose- and say- that he —— of lawful age and —— the appropriator- and claimant of the water and water right mentioned in the foregoing notice and statement of appropriation and claim, and the person- whose name —— subscribed thereto as the appropriator- and claimant-; that he knows the contents of said notice and statement foregoing, and that the matters and things therein stated are true.

—— ——.

Subscribed and sworn to before me this —— day of ——, A. D. 189—.

—— ——.

—— *County, Montana.*

I hereby certify that the within notice of location of water right was filed for record on the —— day of ——, 189—, at —— o'clock — m. and is duly recorded in volume —— of water-right location records on page ——, records of —— County, Montana.

Attest my hand and seal of said county.

—— ——,
County Recorder.

By —— ——,
Deputy.

Fee—$——.

WATER LAWS OF NEBRASKA.

ARTICLE I.

Priority of rights. SEC. 7. As between appropriators, the one first in time is first in right.

ARTICLE II.

Determination of priorities. SEC. 16. It shall be the duty of the State board at its first meeting to make proper arrangements for beginning the determination of the priorities of right to use the public waters of the State, which determination shall begin on streams most used for irrigation, and be continued as rapidly as practicable until all the claims for appropriation now on record shall have been adjudicated. The method of determining the priority and amount of appropriation shall be determined by the said State board, which at its first meeting shall designate the streams to be first adjudicated.

Secretary; measurement of waters. SEC. 17. It shall be the duty of the secretary of the State board of irrigation as soon as practicable after the passage of this act to measure, or cause to be measured, the quantity of water flowing in the several streams of the State and to make a record thereof in the office of said board, and he shall from time to time make such additional measurements as may be necessary, or cause the same to be made, for the information of such board in considering applications for water appropriations and such controversies as may arise regarding the distribution of water.

Purpose of appropriation. SEC. 18. All appropriations for water must be for some beneficial or useful purpose, and when the appropriator or his successor in interest ceases to use it for such purpose the right ceases.

Priorities; order determining. SEC. 19. When the adjudication of a stream shall have been completed it will be the duty of the State board to make and cause to be entered of record in its office an order determining and establishing the several priorities of right to use the water of said stream, and the amount of the appropriation of the several persons claiming water from such stream and the character and kind of use for which such appropriation shall be found to have been made.

Appropriation; priority; amount. SEC. 20. Each appropriation shall be determined in its priority and amount by the time at which it shall have been made, and the amount of water which the works are constructed to carry: *Provided*, That such appropriator shall at no time be entitled to the use of more than he can beneficially use for the purposes for which the appropriation may have been made, and the amount of any appropriation made by means of enlargement of the distributing works heretofore shall be determined in like manner: *Provided*, That no allotment for irrigation shall exceed one cubic foot per second for each seventy acres of land for which said appropriation shall be made.

Certificates; how issued; when recorded. SEC. 21. Within thirty days after the determination of the priorities of appropriation to the use of water of any stream, it shall be the duty of the State board, through its secretary, to issue to each person, association, or corporation a certificate to be signed by the president of the State board and attested by the secretary of said board, setting forth the name and post-office address of the appropriator, the priority number each of appropriation, the amount of water appropriated, and the amount of prior appropriation, and if such appropriation be for irrigation, a description of the land to which the water is to be applied and the amount thereof. Said certificate shall be transmitted by the State board of irrigation, through its secretary, by registered mail to the county clerk of the county in which said appropriation shall have been made, and it shall

be the duty of said county clerk, within ten days after the receipt of said certificate, to record the same in a book especially prepared and kept for that purpose, and to notify the party or parties in whose favor the said certificate is issued of such record, and transmit said certificate to said party or parties on payment of the fees for recording, which fee shall not exceed seventy-five cents for each certificate so recorded.

Appeal from determination. SEC. 22. Any party or number of parties acting jointly who may feel themselves aggrieved by the determination of the State board may have an appeal to the district court of the county within which the appropriation or appropriations of the party or parties so aggrieved may be situated. All persons joining in the appeal shall be joined as appellants, and all persons having interests adverse to the parties appealing or either of them shall be joined as appellees.

Appeal; notice; bond. SEC. 23. The party or parties appealing shall, within sixty days of the determination of the State board which is appealed from and the entry thereof on the records of the board, file in the office of the clerk of the district court to which the appeal is taken a notice in writing stating that such party or parties appeal to the district court from the determination and order of the State board, and upon the filing of such notice the appeal shall be deemed to have been taken: *Provided, however*, That the party or parties appealing shall, within the sixty days mentioned, enter into an undertaking, to be approved by the district court or the clerk thereof, and to be given to all parties in said suit or proceedings, other than the parties appealing, conditioned that the parties giving the said undertaking shall prosecute their appeal to effect and without unnecessary delay, and will pay all costs and damages which the party to whom the undertaking is given or either or any of them may sustain in consequence of such appeal: *Provided*, Such case is decided against the appellant.

Order; service. SEC. 24. The order mentioned in the preceding section shall be entered of record in the records of the State board and the appellant or appellants shall cause a certified copy thereof to be served with the summons hereinafter provided on each of the appellees in the manner provided for serving summons from the district court.

Petition; proceedings; costs. SEC. 25. The appellant or appellants shall, within sixty days after giving the undertaking hereinafter mentioned, file in the office of the clerk of such district court a certified transcript of the order of determination made by the State board and which is appealed from; and the measurement of streams, tributaries, or ditches that may have been made, together with a petition setting out the cause of the complaint of the party or parties appealing to which all parties named as appellants shall be made parties, summons in such appeal to be issued by the clerk of such district court and served in the manner provided by law for the service of summons in action of law; and all proceedings on appeal shall be conducted according to the proceedings of the code of civil procedure. All costs made and accruing by reason of such appeal shall be adjudged to be paid by the party or parties against whom such an appeal shall be finally determined.

Transcript of claims; duty of county clerk. SEC. 26. Within thirty days from the passage of this act it shall be the duty of the county clerk of each of the counties of this State to prepare a full and complete transcript of all the claims to appropriations of water now on file in their respective offices, and to transmit the same without delay to the secretary of the State board by express or registered mail, for which service he shall be paid by the county the sum of five cents per folio to prepare said transcript: *Provided*, That the county clerk may, in place of such abstract, transmit the original record of claims to water that are recorded in books kept especially for the purpose, in which case he shall receive no compensation.

Classification by State board. SEC. 27. Immediately on receipt of said transcripts or the original records, it shall be the duty of the State board to file them in its office, and to classify and arrange said claims by placing all the claims to the waters of one stream and its tributaries together.

Application to appropriate water. SEC. 28. Every person, association, or corporation hereafter intending to appropriate any of the public waters of the State of Nebraska shall, before commencing the construction, enlargement, or extension of any distributing works, or performing any work in connection with said appropriation, make an application to the State board for a permit to make such appropriation. **What to contain.** Said application shall set forth the name and post-office address of the applicant, the source from which said appropriation shall be made, the amount thereof as near as may be, location of any proposed work in connection therewith, the time required for their completion, said time to embrace the period required

for the construction of the ditches thereon and the time at which the application of the water for beneficial purposes shall be made, which said time shall be limited to that required for the completion of the work when prosecuted with diligence, the purpose for which water is to be supplied, and if for irrigation a description of the land to be irrigated thereby, and the amount thereof, and any additional facts which may be required by the State board. On receipt of this application, which shall be of a form prescribed by the State board and to be furnished by the secretary without cost to the applicant, it shall be the duty of the State board, through its secretary, to make a record of the receipt of said application and cause the same to be recorded in its office, and to make a careful examination of the application to ascertain whether it sets forth all the facts necessary to enable the State board to determine the nature and amount of the proposed appropriation. If such an examination shows the application in any way defective, it shall be the duty of the State board to return the same to the applicant for correction. If there is unappropriated water in the source of supply named in the application, and if such appropriation is not otherwise detrimental to the public welfare, the State board, through its secretary, shall approve the same by endorsement thereon and shall make a record of such endorsements in some proper manner in his office and return the same so endorsed to the applicant, who shall, on receipt thereof, be authorized to proceed with the work and to take such measures as may be necessary to perfect such appropriation: *Provided, however*, That the State board, through its secretary, may, upon examination of such application, endorse it approved for a less amount of water than the amount of water stated in the application, or for a less amount of land or for a less period of time for perfecting the proposed appropriation than that named in the application: *And provided further*, That an applicant feeling himself aggrieved by the endorsement made upon his application may take an appeal therefrom to the district court of the county in which may be situated the point of diversion of the proposed appropriation. Such appeal shall be perfected when the applicant shall have filed in the office of the clerk of the district court a copy of the order appealed from, certified by the secretary of the State board as a true copy, together with the petition to such court, setting forth appellant's reason for such appeal. Such appeal shall be heard and determined upon such competent proofs as shall be produced by the applicant and such like proofs as shall be produced by the State board to any person duly authorized in its behalf. If there is no unappropriated water in the source of supply, or if a prior appropriation has been made to water the same land to be watered by the applicant, the State board, through its secretary, shall refuse such appropriation, and the party making such application shall not prosecute such work so long as such refusal shall continue in force.

To be recorded.

When approved.

Appeal allowed from action of board.

When refused.

Map; when filed. SEC. 29. Upon the approval and allowance of an application the applicant shall send to the State board's office within six months thereafter a map or plat, upon a scale of not less than two inches to the mile, showing the location of the course of the distributing works, the source from which the appropriation is taken and the legal subdivisions of the land upon which the water appropriated is to be applied, which said map shall be filed and be preserved in said office as part of the records.

Certificate. SEC. 30. Upon its being made to appear to the satisfaction of the State board that the application in this act provided for has been perfected in accordance with law, and the endorsement thereon by the secretary of the State board, it shall be the duty of said board by the hand of its president, attested by the secretary, to send to the county clerk a certificate of the same character as that described in section twenty-one of this act, which said certificate shall be recorded in the office of the county clerk, and provided for in section twenty-one of this act.

Priority; date. SEC. 31. The priority of such appropriation shall date from the filing of the application in the office of the State board.

Dams. SEC. 38. Any person, corporation, or association hereafter intending to construct any dam for reservoir purposes or across the channel of any running stream above ten feet in height, shall, before beginning such construction, submit the plan of the same to the State board of irrigation for their examination and approval, and no dam above ten feet in height shall be constructed until the same shall have been approved by such board.

Water; public property. SEC. 42. The water of every natural stream not heretofore appropriated, within the State of Nebraska, is hereby declared to be the property of the public, and is dedicated to the use of the people of the State, subject to appropriation as hereinbefore provided.

Priority of appropriation; priority of right. SEC. 43. The right to divert unappropriated waters of every natural stream for beneficial use shall never be denied. Priority of appropriation shall give the better right as between those using the water for the same purpose; but when the waters of any natural stream are not sufficient for the use of all those desiring the use of the same, those using the water for domestic purposes shall have the preference over those claiming for any other purpose, and those using the water for agricultural purposes shall have the preference over those using the same for manufacturing purposes.

Priorities; ditches like running streams. SEC. 44. All ditches constructed for the purpose of utilizing the waste, seepage, swamp, or spring waters of the State shall be governed by the same laws relating to the priority of right as those ditches constructed for the purpose of utilizing the waters of running streams: *Provided*, That the person upon whose lands the waste, seepage, swamp, or spring waters first arise shall have the prior right to the use of such waters for all purposes upon his lands.

Reservoirs. SEC. 56. Any person, company, or corporation desirous of constructing and maintaining a reservoir for the purpose of storing water for irrigation purposes shall have the right to take water from the natural streams of this State when not needed for immediate use for irrigation or domestic purposes; to construct and maintain ditches for the purpose of conducting water to and from such reservoirs and to condemn land for such reservoirs and ditches in the same manner as is provided by law for the condemnation for right of way for ditches, and the owner or owners of such reservoirs shall be liable for all damages arising from leakage or overflow of the water therefrom and by the breaking of the embankments of such reservoir.

Waterworks exempt from taxation. SEC. 61. All ditches, canals, laterals or other works used for irrigation purposes shall be exempt from all taxation, whether State, county, or municipal.

Prosecution of work on appropriation. SEC. 62. Within six months after the approval of any application for water under this act by the State board of irrigation the person, persons, corporation or association making such application shall commence the excavation or construction of the works in which it is intended to divert the water and shall vigorously, diligently, and uninterruptedly prosecute such work to completion, unless temporarily interrupted by some unavoidable and natural cause, and a failure to comply with this section shall work a forfeiture of the appropriation and all rights thereunder.

Deeds and contracts for water rights. SEC. 63. Whenever any person, persons, or corporation owning any irrigation ditch or canal shall convey by deed or contract the right to use the water from such ditch or canal for any tract of land for irrigation purposes, such deed or contract shall be recorded in the county where such land is situated, in the same manner and under the same conditions as deeds for real estate are recorded, and such deed or contract, from the date of recording thereof, shall be binding upon the grantor of such deed or contract, his, their, or its successors or assigns, and all persons, companies, or corporations claiming any interest in such ditch or canal, and no foreclosure or other proceedings to collect money from or subject the sale of the property of the owners of such ditch or canal, shall in any manner impair the right of such grantee, his heirs, administrators or assigns to the use of the water from such ditch or canal in the quantity and manner provided in such deed or contract.

Appeals advanced on docket. SEC. 64. Upon any appeal being taken as is by this act provided, from the board of irrigation to the district court of this State, it shall be the duty of said court to advance such appeal to the head of the trial docket and to give such appeal precedent over other civil cases, in hearing and determination thereof, and if an appeal be taken in such action from the judgment or decree of the district court to the supreme court of the State it shall in like manner be the duty of the supreme court to advance such appeal to the head of its docket for the trial of civil cases and give such causes like precedent as to trial.

Water a natural want. SEC. 65. Water for the purposes of irrigation in the State of Nebraska is hereby declared to be a natural want.

WATER-RIGHT FORMS USED IN NEBRASKA.

Claim for the waters of the State of Nebraska.

Claim. No.——. Priority. No.——. Water division. No.——. District, No.——.

I. —— ——, of the —— county of ——, State of ——, being duly sworn, upon my oath say:

1. That the name of the claimant is —— ——, post-office address, No. ——, street, ——, —— county, ——.
2. That the water is claimed for the purpose of ——.
3. That the name adopted for the ditch or canal is the ——.
4. That the source of the appropriation claimed is ——.
5. That the amount of the appropriation claimed is —— cubic feet per second of time.
6. That the head gate is located on the —— bank of the stream, in —— of section ——, township ——, range —— of the —— principal meridian.
7. That the said ditch or canal, — miles in length, passes through the following sections of land, as shown on the accompanying township plat, viz: (Describe each section through which canal passes, stating township and range.)

(*a*) That the portion of said ditch or canal, —— miles in length, indicated on said plats by a black line, is completed.

(*b*) That the portion of said ditch or canal, —— miles in length, indicated on said plats by a red line, is not completed.

8. That the dimensions of said ditch or canal are (and will be for the uncompleted portions) as follows: Head gate—width in clear —— feet; depth of water on floor at low water —— feet.
9. That the total excavation amounts to —— cubic yards of material, consisting of ——, and that the total length of fluming required is —— feet.

(*a*) That the material thus far removed amounts to —— cubic yards.

(*b*) That the fluming completed amounts to —— feet.

10. That the estimated cost of said ditch or canal is as follows: Earthwork, $——; fluming, $——; head gate, $——; other expenses, $——; total, $——.

(*a*) That the expenditures thus far incurred are as follows: Earthwork, $——; fluming, $——; head gate, $——; other expenses, $——; total, $——.

11. That it is the intention that the said ditch or canal shall supply water to irrigate the following sections or quarter sections of land, viz: (Give sections and quarter sections, stating number, township, and range) amounting in all to —— acres.
12. That the actual work of excavation and construction was begun on the —— day of ——, 18—, and the works —— completed, and the appropriation perfected on or before the —— day of ——, 18—.

(*a*) That this claim is made under and by virtue of rights deemed to have been acquired by ——.

(*b*) That water —— turned into said ditch or canal on or before the —— day of ——, 18—.

13. That the time estimated as necessary to provide for the application of the amount of water herein claimed to the beneficial use above stated is —— years from April 4.

(*a*) That there were —— acres of crops actually irrigated from said ditch or canal during 18—.

14. That the relation which the subscriber to this affidavit bears to said ditch or canal, or other works, is that of ——, and that he is authorized to make this affidavit in behalf of the interests affected.

—— ——.

STATE OF ——, *County of* ——, *ss:*

I hereby certify that the foregoing claim was signed in my presence and sworn to before me by —— —— this —— day of ——, 18—.

—— ——,
Notary Public.

STATE OF NEBRASKA, *Office State Board of Irrigation, ss:*

This instrument was filed for record at —— o'clock —— noon, on the —— day of ——, 18—, and duly recorded in book —— of the record of claims for appropriations, on page ——.

—— ——,
State Engineer, Secretary.

Application for a permit to appropriate the waters of the State of Nebraska.

Permit, No. ——. Water division, No. ——. District, No. ——.

I, —— ——, of the ——, county of ——, State of ——, being duly sworn, upon my oath say:

1. That the name of the applicant herefor is ——; post-office address, No. —— street, —— County, ——.
2. That it is proposed to use the water applied for herein for ——.
3. That the name adopted for the proposed ditch or canal is the ——.
4. That the source of the proposed appropriation is ——.
5. That the amount of the appropriation desired is —— cubic feet per second of time.
6. That it is proposed to locate the head gate on the —— bank of the stream, in —— of section ——, township ——, range —— of the —— principal meridian.
7. That the said ditch or canal will be —— miles in length, and pass through the following sections of land, as shown on the accompanying township plats, viz: (Describe each section through which canal passes, stating township and range.)
8. That the dimensions of the proposed ditch or canal will be as follows: Head gate, width in clear, —— feet; depth of water on floor at low water —— feet.
9. That the material to be removed amounts to —— cubic yards, consisting of —— and that the total length of fluming required is —— feet.
10. That the estimated cost of the proposed construction is as follows: Earthwork, $——; fluming, $——; head gate, $——; other expenses, $——; total, $——.
11. That the proposed ditch or canal is to be built with the intention of supplying water to irrigate the following sections or quarter-sections of land, viz: ——, amounting in all to —— acres.
12. That construction is to be begun within —— of the date hereof, and the proposed works are to be completed, and the appropriation perfected on or before ——.
13. That the time estimated as necessary to provide for the application of the amount of water herein applied for to the beneficial use above stated, is —— years from ——, 189—.

—— ——.

STATE OF ——, *County of* ——, *ss:*

I hereby certify that the foregoing application was signed in my presence and sworn to before me by —— ——, this —— day of ——, 189—.

[SEAL.]

—— ——,
Notary Public.

STATE OF NEBRASKA, *Office State Board of Irrigation, ss:*

This is to certify that the foregoing application has been examined.

—— ——,
—— ——,
State Board of Irrigation.

—— ——,
State Engineer, Secretary.

This is to certify that the foregoing application has been examined and is hereby granted, subject to the following limitations and conditions:

First. The work of excavation or construction shall begin on or before ——, 189—.

Second. The time for completing the work, or perfecting the appropriation, shall extend to ——, 18—.

Third. The time for completing the application of water to the beneficial use indicated shall extend to ——, 1——.

Fourth. The amount of the appropriation shall not exceed —— cubic feet per second, and shall be limited to 1 cubic foot per second of time for each —— acres of land reclaimed on ——, 1——.

—— ——,
—— ——,
State Board of Irrigation.

—— ——,
State Engineer, Secretary.

STATE OF NEBRASKA, *Office State Board of Irrigation*, *ss:*

This instrument was filed for record at —— o'clock, —— noon, on the —— day of ———, 189—, and duly recorded in book —— of the record of applications for appropriations on page ——.

——— ———,
State Engineer, Secretary.

NOTE.—This application, if approved, must be followed within six months by a map or plat on a scale of 2 inches to the mile, showing the location of the distributing works, the source of supply, and the legal subdivisions of land to be irrigated.

Petition for a permit to relocate irrigation works.

Petition, No. ——. No. ——. Water division, No. ——. District, No. ——.

I, ———, of the ———, county of ———, State of ———, being duly sworn, upon my oath say:

1. That the name of the petitioner herefor is ———; post-office address, ———; ——— County, ———.

2. That this is a petition for a permit to relocate ———.

3. That the name of the ditch, canal, or other works referred to in this petition is the ———.

4. That the source of the water supply thereof is ———.

5. That the appropriation therefor is claimed by virtue of rights acquired by ———.

6. (*a*) That the present location of the head gate is on the —— bank of the stream, in —— of section ——, township ——, range —— of the —— principal meridian.

(*b*) That the proposed location of the head gate is on the —— bank of the stream, in —— of section ——, township ——, range —— of the —— principal meridian.

7. That the said ditch or canal —— miles in length passes through the following quarter sections of land, as shown on the accompanying township plats, viz: (Describe each quarter section through which ditch or canal passes, stating township, range, etc.)

(*a*) That the portions of said ditch or canal, —— miles in length, indicated on said plats by a continuous black line, is completed.

(*b*) That the portion of said ditch or canal, —— miles in length, indicated on said plats by a dotted black line, is not completed.

8. That the said ditch or canal, when relocated, will be —— miles in length and pass through the following quarter sections of land, as shown on the accompanying township plats, viz: (Describe each quarter section through which ditch or canal passes, stating township, range, etc.)

(*a*) That the portions of said ditch or canal, —— miles in length, indicated on said plats by continuous and dotted black lines, show course thereof as originally located.

(*b*) That the portion of said ditch or canal, —— miles in length, indicated on said plats by red lines, show course thereof as relocated.

9. That the estimated cost of proposed relocation is as follows: Earthwork, $——; fluming, $——; head gate, $——; other expenses, $——; total, $——.

10. That the work of relocation is to be begun within —— of the date hereof, and the same will be completed on or before ———.

——— ———.

STATE OF ———, *County of* ———, *ss:*

I hereby certify that the foregoing petition was signed in my presence and sworn to before me by ——— ———, this —— day of ———, 18—.

[SEAL.]

——— ———,
Notary Public.

STATE OF NEBRASKA, *Office State Board of Irrigation*, *ss:*

This is to certify that the foregoing petition has been examined.

—— ——,

—— ——,

State Board of Irrigation.

—— ——,

State Engineer, Secretary.

STATE OF NEBRASKA, *Office State Board of Irrigation*, *ss:*

This instrument was filed for record at —— o'clock, —— noon, on the —— day of ——, 189–, and duly recorded in book —— of the record of petitions for relocations, on page ——.

—— ——,

State Engineer, Secretary.

NOTE.—This petition, if approved, must be followed within sixty days by a map or plat on a scale of 2 inches to the mile, showing the location of the diverting and distributing works as relocated, the source of supply, and the legal subdivisions of land irrigated.

WATER LAWS OF SOUTH DAKOTA.

SEC. 1. That all surface waters in the State of South Dakota are hereby appropriated to the use and benefit of the public. (Chapter 75, Session Laws 1897.)

SEC. 1. That all surplus water above the normal amount in lakes, rivers, creeks, or other bodies of water is hereby appropriated to the use and benefit of the people of this State. (Chapter 77, Session Laws 1897.)

SEC. 1. It shall be lawful for any person, company, or corporation to construct and maintain, or permit to be constructed and maintained, a dam or dams upon and adjacent to their own lands in any of the natural streams of the State, and to take from said streams any unappropriated water not needed for immediate use for domestic and irrigating purposes, and also to construct and maintain, or permit to be maintained and constructed, reservoirs for the purpose of storing water, taken from said streams to be used for irrigating agricultural lands; and to construct and maintain ditches, sluiceways, or waterways for carrying such water to and from such streams or to and from such reservoirs, and to construct and maintain water wheels and machinery, to be propelled by the waters of such streams or otherwise, for the purpose of raising the water therefrom for the aforesaid purposes, or to keep, maintain, and use other machinery and appliances for like purposes: *Provided*, That no dam shall be built or constructed so as to cause the waters of such stream to flow out of the natural channel or banks of such stream at its ordinary stage, and the party damaging or injuring the lands or possessions of another by reason of such dams or reservoirs shall be liable to the party so injured for the actual damage occasioned thereby. (Chapter 104, Session Laws 1895.)

Construction of artesian wells lawful.

SEC. 1. It shall be lawful for any person or persons, corporation or corporations, company or companies, to construct artesian wells upon lands owned or leased by such person, company, or corporation for the purpose of power and the irrigation of lands for agricultural purposes, and for any and all purposes for which said water from such wells may be utilized. (Chapter 103, Laws 1890.)

Who may construct.

SEC. 2. Any person or company, or any corporation, formed under the laws of this State for the purposes aforesaid, may, for the purpose of laying water pipes, constructing ditches and waterways, cause such examination and survey to be made as may be necessary to the location of the most advantageous route, and for such purpose such person, company, or corporation, by themselves, their agent, or servants, may enter upon the lands of any other person, company, or corporation, and shall only be liable for actual damages sustained by reason of such entrance and examination: *Provided*, That no routes for waterways shall be located without the written consent of the owner, within fifteen rods of the dwelling house or other buildings on the premises, or across any orchard or garden, without such written consent.

Surplus water.

SEC. 5. For the purpose of disposing of the surplus water from any artesian well it shall be lawful for the said person, company, or corporation to construct the necessary waterways from said well on the routes as provided in sections two and four of this act.

Surplus water.

SEC. 18. Whenever any waterway shall be located and constructed under the provisions of this act across the lands of any person other than the lands owned by the proprietors of said well, such person may apply to the proprietors for the right to use the surplus water flowing in such waterway or ditch to irrigate his own lands, and the said proprietor shall allow him to use and appropriate such water by paying a just rental therefor. The rates to be paid and terms and conditions under which said surplus water may be used shall, upon proper application by the parties, be fixed and defined in a just and equitable manner by the board of county commissioners at a regular or special meeting *thereof*, and either party may appeal to the circuit court of the county within

which the said waterway is located from the decision of said board, in the manner provided by law for appeals from said board, and the decision of said circuit court shall be final: *Provided*, That nothing in this section contained shall be construed to prevent the use of all the water which may flow from said well by the proprietor thereof upon his own lands, except that when the said proprietor shall own land located beyond the lands across which said ditch is constructed, an equitable adjustment of the rights of all the parties shall be made by the said board, subject to appeal as aforesaid.

Public use. SEC. 19. Whenever waterways or ditches are located or constructed along any public highway the water which may be flowing therein shall be for the use of the public: *Provided*, That when any owner or occupant of the lands adjoining or lying along such highway desires to use any portion of the water flowing in such highway or ditch, he shall make application to the proprietor of said well, and the adjustment of the amount of rental to be paid to said proprietor for the use of such water and the terms and conditions thereof shall be made by the board of county commissioners, as previded in section eighteen of this act, with right of appeal as therein provided; but the right of the use and appropriation of such water shall be subject to the rights of the public therein.

Use of water from private wells limited. SEC. 42. Any person, association, or corporation owning land shall have the right to sink or bore an artesian well or wells on his, their, or its lands for the purpose of procuring water for domestic use, for irrigation, or for manufacturing purposes; but in wells hereinafter constructed, no more water shall be appropriated by such person, association, or corporation than is needed for said purpose when such additional use of water interferes with the flow of wells on adjacent lands. (Chapter 80, Laws 1895.)

Location of wells. SEC. 43. In locating wells in townships which have established and put down wells under the provisions of this act for public use, or by private parties, due regard shall be had for their proper distribution in order that the flow of the wells may be properly equalized and least likely to interfere with each other. Should any well in such township, public or private, be located so near any well already completed or in process of completion as to be likely to interfere with the same, any person may complain in writing to the State engineer, who shall, without delay, proceed to examine the locality and determine from its topography and the proximity of the wells whether in his judgment the wells as located would unduly interfere with the one already completed or in course of completion. If in his judgment there will be no material interference, the location will not be changed, but if in his opinion the well as located will materially interfere with the one completed or in the course of completion, he shall change the location of said well to some more suitable locality: *Provided*, That when permanent buildings have been located on any farm prior to the sinking of any artesian well on any adjoining farm, this act shall not be construed as prohibiting the agent or proprietor of said farm from sinking an artesian well at or near said building without reference to the proximity of any other artesian well. The State engineer shall, within five days after said examination, make a written statement of his decision and file the same or a copy thereof in the office of the clerk of the circuit court of the county wherein the said wells are located. Any person aggrieved by the decision of the State engineer may, within ten days after the filing of his decision in the office of the clerk of the circuit court, and upon such appeal the question shall be tried de novo. (Chapter 80, Laws 1895.)

Flow and pressure of wells to be determined. SEC. 44. The State engineer is hereby authorized and it is made his duty to measure or cause to be measured the flow and pressure of all artesian wells established and put down under the provisions of this act, public and private, at such times as he may deem proper, for the purpose of determining the increase or diminution of the flow or pressure of said well, and is hereby authorized to enter upon any grounds for the purposes aforesaid, and the owner or owners of such well or wells are hereby directed to furnish the necessary material to construct a suitable weir to measure the flow, and all reasonable conveniences shall be afforded for this purpose.

Water shall not be wasted. SEC. 46. No person controlling an artesian well shall suffer or permit the waters thereof to flow to waste unless, and so far as reasonably necessary, to prevent the obstruction thereof, or to flow or to be taken therefrom save for beneficial uses: *Provided*, This shall not be construed as to prevent the reasonable use of said water for the necessary irrigation of trees standing along or upon any street, road, or highway, or for ornamental ponds or fountains, or the propagation of fish.

Inspection of wells. SEC. 47. Any township supervisor, the county commissioners, road overseers, and aldermen, or other city officers within their respective townships, counties, cities, and towns, upon complaint of any person that the proprietor of any artesian well, or person controlling the same, is wont to suffer the waters thereof to unreasonably run to waste therefrom, or have in any respect violated this act, may, at any reasonable hour of the day or night, enter upon any premises where such well is situated, for inspecting the same and for ascertaining whether there is sufficient cause for such complaint, and in order to institute, or cause to be instituted, criminal prosecutions for any violations of this act, and every person sinking or boring for an artesian well upon his own land, or suffering others to do so, shall be deemed in law to expressly license such entry of the officers aforesaid, or any of them, for the purposes of such inspection and examination.

Number of wells in each township; when located. SEC. 2. Whenever a majority of the qualified electors of any civil township in the State of South Dakota shall make an application in writing to the State engineer of irrigation, requesting him to locate within said civil township artesian wells, not to exceed nine in number if said wells shall be six inches in diameter, and not to exceed sixteen in number if said wells shall be four and one-half inches in diameter, for the purpose of supplying the public with water, it shall be the duty of said engineer, within twenty days from the presentation to him of said application, to locate, or cause to be located, in said township the number of wells mentioned in said application, not exceeding nine if said wells be six inches in diameter, and not exceeding sixteen if said wells be four and one-half inches in diameter, at such places as shall, in the judgment of the State engineer of irrigation, best subserve the interests of the landholders of the township. The majority of electors is to be determined by the vote of the civil township, as shown by the poll list thereof at the last preceding election. (Chapter 80, Session Laws 1895.)

Application and report to be filed. SEC. 3. The State engineer shall, within thirty days after the receipt of said written application, file the same, together with his report locating said wells, in the office of the register of deeds in and for said county.

Report to contain what. SEC. 4. The report of the State engineer, mentioned in section three of this act, shall state the number of wells, the size of each well, and the exact location of the same, together with a full description thereof.

Application for use of water. SEC. 18. At any time after the contract for sinking of any well has been completed any person owning land in said township desiring the use of any water from said well for the purpose of irrigation shall make to the board of supervisors of the township an application, in writing, describing the tract of land to be irrigated and the number of acres to which water is to be applied, and that the applicant is willing to pay for the same in acre-feet.

Board of supervisors to contract for use of water. SEC. 19. Within ten days after the filing of said application for water the board of supervisors shall enter into a contract to furnish water to the owner for the land described at a price per acre-foot of water to be fixed in said contract, which shall in no event be less than one dollar per acre-foot per annum, which shall in no event be used and employed for the maintenance and payment of said well until the well, ditches, and reservoirs are fully paid for out of the rentals: *Provided*, That whenever the owner of said land applies to the board to furnish him water that the board may provide that the water be conveyed to the land to be irrigated at said owner's expense: *Provided further*, That for the purpose of conveying said water to the land proposed to be irrigated the owner thereof, or the township, shall have the right of condemnation, as provided in chapter one hundred and three, laws of eighteen hundred and ninety. The lessees, or any number or one of them, obtaining water flowing from any well constructed under the provisions of this act shall have the right at any time to purchase from the township, by and with the consent of a majority of the freeholders of said township, determined at a general or special election called by the board of supervisors for that purpose, in which said well is located, the well from which he or they may obtain water, by paying to said township the cost of construction of said wells, ditches, and reservoirs, together with the amount for which said well was bonded. In case the waters from any such well are not leased to any person, then the board of supervisors of such township shall have the power and right, by and with the consent of a majority of the freeholders of said township, determined at a general or special election called by the board of supervisors for that purpose,

to sell unto any person owning land in the vicinity where such well is located such well constructed under the provisions of this act for the amount of bonds issued for the construction of said well, ditches, and reservoirs: *Provided*, That said land be so situated as to be susceptible of irrigation from the waters from said well.

Application and contract to be filed with the register of deeds.

SEC. 20. The board of supervisors of the township shall file or caused to be filed for record in the office of the register of deeds of the county in which said township is located the said application and a duplicate of the water contract, which shall be recorded by the register of deeds, and from that time the said rights given under the said contract shall run with the title of the land, and shall not be severable therefrom until default is made in the payment of water rent, which default must have continued thirty days before the right to the water mentioned in said contract shall be severable from the land.

Lien upon land for water rent.

SEC. 21. Every township having constructed wells under this act shall have a lien upon the lands mentioned in said water contract from the time said contract is filed with the register of deeds, as provided in section twenty hereof, and may foreclose the said lien upon the said lands described in the contract by advertisement, as now or as may be hereafter provided for the foreclosure of real estate mortgages.

Water rent; how collected; disposition of.

SEC. 22. It shall be the duty of every township treasurer to collect the water rents mentioned in this act, and immediately pay the same to the county treasurer of the county, whose duty it is to set the same aside as a fund, out of which he is directed to pay the interest upon the water bonds of the township as said interest shall become due.

Township board may levy tax.

SEC. 23. In case there shall not have been sufficient money paid into the county treasury for water rents on the first day of April in any year to pay the amount of interest on the water bonds for the year, then it shall be the duty of the civil officers of said township to levy and collect a sufficient tax to pay the interest upon the said bonds; and it is hereby made the duty of the township board to levy upon the taxable property of the civil township a sufficient tax to pay the interest upon the water bonds whenever there shall be an insufficiency of funds from water rent to pay the interest as in this section provided, and after five years a sufficient tax shall be levied upon the taxable property of the civil township to provide a sinking fund for the payment of the principal of the bonds when due, but in no event shall such tax exceed three per cent upon the taxable property of the township in any one year.

Wells for filling artificial reservoirs, etc.

SEC. 30. If at any time the petitioners for artesian wells, as herein provided, shall state in their petition to the State engineer of irrigation that they desire said wells, or any of them, sunk for the purpose of filling lake beds, streams, or artificial reservoirs in said township for public purposes, said wells shall be sunk, and all the provisions of this act in reference to obtaining the same shall apply to such wells, excepting that the constant flow of said wells shall be allowed unless, in the judgment of the State engineer, the flow of other artesian wells used for domestic and irrigation purposes are diminished thereby, and it is hereby made the duty of the township board of supervisors, by proper dams and other appliances, to retain as far as possible the waters from said wells within the township providing for said wells.

Number of wells may exceed sixteen.

SEC. 32. Whenever the application to the State engineer for artesian wells shall call for a well smaller than four and one-half inches in diameter, authority is hereby given for the location and sinking in said township of more than sixteen artesian wells.

Rules for use of water.

SEC. 34. The State engineer may, and when requested by the township board shall, prescribe rules and regulations for the distribution and use of water from public wells not in conflict with law, subject to the approval of the township board of supervisors.

Record to be kept by the person sinking well.

SEC. 35. It is hereby made the duty of the township board to embody in the contract for the sinking of said public artesian wells a provision that the person sinking said wells make a record of the depth of each well and the formations entered or passed through in the construction of the same, and such provision is hereby made the essence of the contract, and a violation thereof shall be construed to be a violation of the contract.

Water to be applied; how. SEC. 36. The waters derived from artesian wells pursuant to this act shall be applied for the purposes of irrigation, for domestic purposes, which is hereby defined to mean for household use, for the supply of domestic animals kept with and for the use of the household and farm, and the watering and sustaining of trees, grass, flowers, and shrubbery about the house of the consumer in an area not exceeding one-half acre of land, and for manufacturing purposes: *Provided*, That whenever the use of said wells for manufacturing purposes will in no manner obstruct or materially diminish the waters for irrigation purposes the board of township supervisors are authorized to lease the power for such manufacturing purposes as in their judgment will best subserve the interest of the people; said license shall not be for a period exceeding ten years: *Provided further*, That the lessee, his heirs or assigns, may at the end of ten years renew said lease by paying the rental at which said power shall be appraised at the end of that period, and the moneys arising from the rentals of said power shall be paid into the county treasury and be used as a fund out of which shall be paid the interest and principal of said water bonds.

Public watering place provided. SEC. 37. The State engineer may, at the expense of the township, conduct the water from each well to a point on the public highway nearest thereto, and provide for the reception of said water a tank not less than ten feet in length, three feet in width, and two feet in depth, in which sufficient water shall be kept to supply the general public for the purpose of watering stock and other domestic uses.

WATER-RIGHT FORMS USED IN SOUTH DAKOTA.

Form of notice required under Territorial law.

Location certificate (water right).

Know all men by these presents, that the undersigned, ——— ———, hereby locates and appropriates the waters of ——— stream, creek, or gulch, to be taken and diverted therefrom at a point on the same ——— and carried thence by ditch and flume on a line as near as may be ——— to ———, the place of intended use.

The number of inches of water claimed and appropriated is ——— miners' inches.

The purpose of the appropriation is for mining, milling, manufacturing, and domestic uses.

Date of appropriation ——— ———, 18—. Date of posting at the head of ditch ———, 18—. Date of certificate ——— ———, 18—.

——— ———,

——— ———.

WATER LAWS OF WYOMING.

CONSTITUTION OF WYOMING.

ARTICLE I.

Water control in State. SEC. 31. Water being essential to industrial prosperity, of limited amount, and easy of diversion from its natural channels, its control must be in the State, which, in providing for its use, shall equally guard all the various interests involved.

ARTICLE VIII.

Water is property of State. SECTION 1. The water of all natural streams, springs, lakes, or other collections of still water, within the boundaries of the State, are hereby declared to be the property of the State.

Board of control. SEC. 2. There shall be constituted a board of control, to be composed of the State engineer and superintendents of the water divisions; which shall, under such regulations as may be prescribed by law, have the supervision of the waters of the State and of their appropriation, distribution, and diversion, and of the various officers connected therewith, its decisions to be subject to review by the courts of the State.

Appropriation. SEC. 3. Priority of appropriation for beneficial uses shall give the better right. No appropriation shall be denied except when such denial is demanded by the public interests.

Water divisions. SEC. 4. The legislature shall by law divide the State into four water divisions and provide for the appointment of superintendents thereof.

State engineer. SEC. 5. There shall be a State engineer, who shall be appointed by the governor of the State and confirmed by the senate; he shall hold his office for the term of six years, or until his successor shall have been appointed and shall have qualified. He shall be president of the board of control, and shall have general supervision of the waters of the State and of the officers connected with its distribution. No person shall be appointed to this position who has not such theoretical knowledge and such practical experience and skill as shall fit him for the position.

ARTICLE XIII.

May acquire water by appropriation and condemnation. SEC. 5. Municipal corporations shall have the same right as individuals to acquire rights, by prior appropriation and otherwise, to the use of water for domestic and municipal purposes, and the legislature shall provide by law for the exercise upon the part of incorporated cities, towns, and villages of the right of eminent domain for the purpose of acquiring from prior appropriators upon the payment of just compensation, such water as may be necessary for the well being thereof and for domestic uses.

SESSION LAWS OF WYOMING, 1890-91.

CHAPTER VIII.

Water divisions defined. SECTION 1. The State of Wyoming is hereby divided into four water divisions, denominated water division No. 1, water division No. 2, water division No. 3, water division No. 4, respectively.

SEC. 2.[1] Water division No. 1 shall consist of all lands within this State drained by the North Platte River and the tributaries of the North Platte River and the

[1] As amended, 1895.

South Platte River, Snake River (a tributary of Green River) and its tributaries, and Running Water Creek and its tributaries.

SEC. 3.[1] Water division No. 2 shall consist of all lands within this State drained by the tributaries of the Yellowstone and Missouri rivers north of the watershed of the North Platte and Running Water Creek and east of the summit of the Big Horn Mountains.

SEC. 4.[1] Water division No. 3 shall consist of all lands within this State drained by the Big Horn River and its tributaries and by Clarks Fork and its tributaries.

SEC. 5. Water division No. 4 shall consist of all lands within this State drained by the Green, Bear, and Snake rivers, and the tributaries thereof; except Snake River, a tributary of Green River, and its tributaries.

Salary of engineer. SEC. 6. The State engineer shall receive a salary of two thousand five hundred dollars per annum, payable in monthly installments by the State treasurer upon warrants drawn by the State auditor.

His office. SEC. 7. The State engineer shall keep his office at the State capital in the capitol building.

His oath and bond. SEC. 8. Before entering upon the duties of his office he shall take and subscribe an oath, before some officer authorized by the laws of the State to administer oaths, to faithfully perform the duties of his office, and shall file with the secretary of State said oath, and his official bond in the penal sum of five thousand dollars, with not less than two sureties, to be approved by the governor of the State, and conditioned for the faithful discharge of the duties of his office and for delivery to his successor, or other officer appointed by the governor to receive the same, all moneys, books, and other property belonging to the State then in his hands or under his control, or with which he may be legally chargeable as such officer. No person shall be appointed as such State engineer who is not known to have such theoretical knowledge and practical skill and experience as shall fit him for the position.

Duties of engineer. SEC. 9. The State engineer shall perform such duties as are prescribed in the law defining the duties of the board of control, and in addition shall make or cause to be made measurements and calculations of the discharge of streams from which water shall be taken for beneficial purposes, commencing such work upon those streams as are most used for irrigation or other beneficial purposes. He shall collect facts and make surveys to determine the most suitable location for constructing works for utilizing the water of the State, and to ascertain the location of the lands best suited for irrigation. He shall examine reservoir sites and shall, in his reports, embody all the facts ascertained by such surveys and examinations, including, wherever practicable, estimates of the cost of proposed irrigation works and of the improvement of reservoir sites. He shall become conversant with the waterways of the State and the needs of the State as to irrigation matters, and in his reports to the governor he shall make such suggestions as to the amendment of existing laws, or the enactment of new laws, as his information and experience shall suggest, and he shall keep in his office full and proper records of his work, observations, and calculations. All of which shall be the property of the State.

Assistant engineer. SEC. 10. The State engineer shall have the power to employ an assistant engineer, at an expense not to exceed twelve hundred dollars per year, and to employ other assistants at a total additional expense not to exceed five hundred dollars per year; such assistant engineer and such additional assistants to be paid out of any money appropriated for that purpose, on certificates of the State engineer showing the amount of such employment and the compensation therefor, and on the presentation of such certificate to the State auditor he shall issue a warrant on the State treasurer for the amount thereof.

Traveling expenses allowed. SEC. 11. When the State engineer or his assistant engineer is called away from his office he shall be entitled to his actual traveling expenses, which shall be paid out of any money appropriated for that purpose on the certificate of said State engineer; such certificate shall be presented to the State auditor, who shall thereupon draw upon the State treasurer for the amount thereof.

Report of engineer. SEC. 12. The State engineer shall prepare and render to the governor biennially, and oftener if required, full and true reports of his work touching all the matters and duties devolving upon him by virtue of his office, which report shall be delivered to the governor on or before the thirtieth day of November of the year preceding the regular session of the legislature.

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[1] As amended, 1895.

Division Superintendents.

Appointment and term. SEC. 13. There shall be one superintendent for each of the water divisions by this act created, who shall be appointed by the governor, with the consent of the senate, who shall hold his office for four years, or until his successor is appointed and shall have qualified, and who shall reside in the water district [division] for which he is appointed. The superintendent of each water division shall have immediate direction and control of the acts of the water commissioners and of the distribution of water in his water division, and shall perform such duties as shall devolve upon him as a member of the board of control.

Duties. SEC. 14. Said division superintendent shall have general control over the water commissioners of the several districts within his division. He shall, under the general supervision of the State engineer, execute the laws relative to the distribution of water in accordance with the rights of priority of appropriation, and perform such other functions as may be assigned to him by the State engineer.

May make regulations. SEC. 15. Said division superintendent shall, in the distribution of water, be governed by this act and acts now in force, but, for the better discharge of his duties, he shall have authority to make such other regulations to secure the equal and fair distribution of water, in accordance with the rights of priority of appropriation, as may, in his judgment, be needed in his division: **Proviso.** *Provided*, Such regulations shall not be in violation of any part of this act or other laws of the State, but shall be merely supplementary to and necessary to enforce the provisions of the general laws and amendments thereto.

Appeal from. SEC. 16. Any person, ditch company, or ditch owner who may deem himself injured or discriminated against by any such order or regulations of such division superintendent shall have the right to appeal from the same to the State engineer, by filing with the State engineer a copy of the order or regulation complained of and a statement of the manner in which the same injuriously affects the petitioner's interest. The State engineer shall, after due notice, hear whatever testimony may be brought forward by the petitioner, either orally or by affidavit, and through the division superintendent shall have power to suspend, amend, or confirm the order complained of.

Water commissioners to report to superintendent; reports filed; order of superintendent. SEC. 17. All water commissioners shall make reports to the division superintendent of their division as often as may be deemed necessary by said superintendent. Said reports shall contain the following information: The amount of water necessary to supply all the ditches, canals, and reservoirs of that district; the amount of water actually coming into the district to supply such ditches, canals, and reservoirs; whether such supply is on the increase or decrease; what ditches, canals, and reservoirs are at that time without their proper supply, and the probability as to what the supply will be during the period before the next report will be required; and such other further information as the division superintendent of that division may suggest. Said division superintendent shall carefully file and preserve such reports, and shall from them ascertain what ditches, canals, and reservoirs are and what are not receiving their proper supply of water; and if it shall appear that in any division of that district (district of that division) any ditch, canal, or reservoir is receiving water whose priority postdates that of the ditch, canal, or reservoir in another district as ascertained from his register, he shall at once order such post-dated ditch, canal, or reservoir shut down and the water given to the elder ditch, canal, or reservoir; his orders being directed at all times to the enforcement of priority of appropriation, according to his tabulated statement of priorities, to the whole division and without regard to the district within which the ditches, canals, or reservoirs may be located. The reports of water commissioners to the division superintendents of irrigation shall be filed and kept in the office of State engineer.

Pay of superintendent; his oath and bond. SEC. 18.[1] Said division superintendents of water divisions Nos. 2, 3, and 4 shall each be paid eight dollars per day for every day actually consumed in the performance of his duties as such division superintendent. Superintendent of water division No. 1 shall receive annually a salary of one thousand five hundred dollars payable in monthly installments, and shall, in addition, be paid his actual traveling expenses when called away from home to the performance of his duties. Before entering upon the duties of his office such division superintendent shall

[1] As amended, 1899.

take and subscribe an oath, before some officer authorized by the laws of the State to administer oaths, to faithfully perform the duties of his office, and file with the secretary of state said oath and his official bond in the penal sum of two thousand five hundred dollars, with not less than two sureties, to be approved by the governor of the State, and conditioned for the faithful discharge of the duties of his office.

How constituted; meetings and officers.

SEC. 19.[1] There is hereby constituted a board of control, composed of the State engineer and the superintendents of the four water divisions. Said board shall have an office with the State engineer, in the capitol, at Cheyenne, and shall hold two meetings each year for the transaction of such business as may come before it, the first of said meetings to begin on the second Wednesday in March and the second on the third Wednesday in October. The State engineer shall be ex officio president of said board, and shall have the right to vote on all questions coming before it, and a majority of all the members of said board shall constitute a quorum to transact business. The superintendent of water division No. 1 shall be the secretary of the State board of control, and it shall be his duty to keep a full, true, and complete record of the transactions of said board and to certify under seal all certificates of appropriation of water made in accordance with the provisions of this act.

Duty at first meeting; measurement of streams; taking testimony; notice to claimants; statement of claimant.

SEC. 20. It shall be the duty of said board at its first meeting to make proper arrangements for beginning the determination of the priorities of right to the use of the public waters of the State, which determination shall begin on the streams most used for irrigation and be continued as rapidly as practicable until all the claims for appropriation now on record shall have been adjudicated. The method of determining the priority and amounts of appropriation shall be as follows:

The board of control shall decide at their first meeting the streams to be first adjudicated, and shall fix a time for beginning the taking of testimony and the making of such examination as will enable them to determine the rights of the various claimants. Said board shall prepare a notice, setting forth the date when the engineer will begin a measurement of the stream and the ditches diverting the water therefrom, and a place and a day certain when the superintendent of the water division in which the stream to be adjudicated is situated, shall begin the taking of testimony as to the rights of the parties claiming water therefrom. Said notice shall be published in two issues of a newspaper having general circulation in the county in which such stream is situated, the publication of said notice to be at least thirty days prior to the beginning of taking testimony by said division superintendent, or for the measurement of the stream by the State engineer or his assistant, and the superintendent taking such testimony shall have the power to adjourn the taking of evidence from time to time and from place to place: *Provided*, All places appointed and adjourned to by the superintendent shall be so situated, as related to the streams, as shall best suit the proper convenience of the persons interested in the determination of such priorities and appropriations. It shall also be the duty of said division superintendent to mail to each party having a recorded claim to the waters of such stream, by registered mail, a similar notice, setting forth the date when the State engineer or his assistant will begin the examination of the stream and ditches diverting water therefrom, and also the date when the superintendent will begin the taking of testimony and the date when the taking of such testimony by said division superintendent shall close, and he shall, in addition, inclose with said notice a blank form, on which said claimant shall present in writing all the particulars showing the amounts and dates of appropriations to the use of water of said stream to which he lays claim; the said statement to include the following:

The name and post-office address of the claimant.

The nature of the use on which the claim for an appropriation is based.

The time of the commencement of such use; and if distributing works are required.

The date of beginning of survey.

The date of beginning of construction.

The date when completed.

The date of beginning and completion of enlargements.

The dimensions of the ditch as originally constructed and as enlarged.

The date when water was first used for irrigation or other beneficial purposes, and if used for irrigation, the amount of land reclaimed the first year; the amount

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[1] As amended, 1895.

in subsequent years, with the dates of reclamation, and the amount of land such ditch is capable of irrigating; the character of the soil and the kind of crops cultivated, and such other facts as will show a compliance with the law in acquiring the appropriation and the rank of priority claimed.

Statements to be under oath. SEC. 21. Each of said claimants shall be required to certify to his statements under oath, and the superintendent of the water division in which the testimony is taken is hereby authorized to administer such oath, which shall be done without charge to the claimant, as also shall be the furnishing of blank forms for said statement.

Superintendent takes testimony, when; notice upon completion of testimony. SEC. 22. Upon the date named in the preceding notice the division superintendent shall begin the taking of said testimony, and shall continue until said testimony shall be completed: *Provided*, That in case the division superintendent of any water district [division] is directly or indirectly interested in the water of any stream of his division, the taking of evidence in so far as relates to said stream shall be under the direction of the division superintendent of the next nearest water division, or under the direct personal supervision of the State engineer, as may be deemed most expedient. Upon the completion of the taking of evidence by the division superintendent it shall be his duty to at once give notice, in one issue of some newspaper of general circulation in the county where such determination is, and by registered mail, to the various claimants, that upon a certain day and at a place named in the notice all of said evidence shall be open to the inspection of the various claimants, and said superintendent shall keep said evidence open to inspection at said place not less than one day and not more than five days.

Contests. SEC. 23.[1] Should any person, corporation, or association of persons owning any irrigation works claim[ing] any interest in the stream or streams involved in the adjudication, desire to contest any of the rights of the persons, corporations, or associations who have submitted their evidence to the superintendent as aforesaid, such persons, corporations, or associations shall, within fifteen days after the testimony so taken shall have been opened to public inspection, as provided in section twenty-two of said act, in writing, notify the superintendent of the water division in which is located said irrigation works or stream or streams, stating with reasonable certainty the ground of their proposed contest, which statement shall be verified by the affidavit of the contestant, his agent or attorney, and the said division superintendent shall notify the said contestant and the person, corporation, or association whose rights are contested, to appear before him at such convenient place as the superintendent shall designate in such notice. Said superintendent shall also fix the time, both as to the day and hour, for the hearing of said contest, which date shall not be less than thirty nor more than sixty days from the date the notice is served on the party, association, or corporation, which notice and the return thereof shall be made in the same manner as summons are served in civil actions in the district court of this State.

Superintendents of water divisions shall have power to adjourn hearings from time to time upon reasonable notice to all the parties interested, and to issue subpœnas and compel the attendance of witnesses to testify upon such hearings, which shall be served in the same manner as subpœnas issued out of the district courts of the State, and shall have the power to compel such witnesses so subpœnaed to testify and give evidence in said matter; said witnesses shall receive fees as in civil cases, to be paid by the party or parties against whom the contest shall be finally determined.

The evidence on such proceeding shall be confined to the subjects enumerated in the notice of contest.

The superintendent shall require a deposit of eight dollars from each party for each day he shall be so engaged in taking evidence on said contest.

Upon the final determination of the adjudication of the matters by the board of control, an order shall be entered directing that the money so deposited shall be refunded to the persons, associations, or corporations, in whose favor such contest shall be determined, and that all moneys deposited by other parties therein shall be turned over by the superintendent to the State treasury to the credit of the fund provided for the maintenance of the board of control.

Upon the completion of the evidence in the original hearing before the superintendent, as provided in the previous section, and the evidence taken in all contests, it shall be his duty to transmit all the evidence and testimony in said adjudication to the office of the board of control, in person or by registered mail.

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[1] As amended, 1895.

Measurement of stream and ditches. SEC. 24. It shall be the duty of the State engineer, or some qualified assistant, to proceed at the time specified in the notice to the parties on said stream to be adjudicated, to make an examination of said stream, and the works diverting water therefrom, said examination to include the measurement of the discharge of said stream, and of the carrying capacity of the various ditches and canals diverting water therefrom; an examination of the irrigated lands, and an approximate measurement of the lands irrigated, or susceptible of irrigation from the various ditches and canals, which said observations and measurements shall be reduced to writing, and made a matter of record in his office, and it shall be the duty of the State engineer to make, or cause to be made, a map or plat, on a scale of not less than one inch to the mile, showing, with substantial accuracy, the course of said stream, the location of each ditch or canal diverting water therefrom, and the legal subdivisions of land which have been irrigated, or which are susceptible of irrigation, from the ditches and canals already constructed.

Order determining priorities. SEC. 25. At the first regular meeting of the board of control, after the completion of such measurement by the State engineer, and the return of said evidence by said division superintendent, it shall be the duty of the board of control to make, and cause to be entered of record in its office, an order determining and establishing the several priorities of right to the use of waters of said stream, and the amounts of appropriations of the several persons claiming water from such stream, and the character and kind of use for which said appropriation shall be found to have been made. Each appropriation shall be determined in its priority and amount by the time by which it shall have been made and the amount of water which shall have been applied for beneficial purposes: *Provided*, That such appropriator shall at no time be entitled to the use of more water than he can make a beneficial application of on the lands for the benefit of which the appropriation may have been secured; and the amount of any appropriation made by reason of an enlargement of distributing works shall be determined in like manner: *Provided*, That no allotment shall exceed one cubic foot per second for each seventy acres of land for which said appropriation shall be made.

Certificate of appropriation. SEC. 26.[1] Within a reasonable time after the determination of the priorities of appropriation of the use of waters of any stream, it shall be the duty of the secretary to issue to each person, association, or corporation represented in such determination, a certificate, to be signed by the State engineer, as president of the board of control, and attested under seal by the secretary of said board, setting forth the name and post-office address of the appropriator; the priority number of such appropriation; the amount of water appropriated; and if such appropriation be for irrigation, a description of the legal subdivisions of land to which said water is to be applied. Such certificate shall be transmitted by said State engineer, or by a member of the board of control in person, or by registered mail, to the county clerk of the county in which such appropriation shall have been made, and it shall be the duty of said county clerk, on receipt of the same, to notify said party or parties in whose favor the said certificate is issued, that on payment of the fee for recording, which fee shall be seventy-five cents, he will record the same; and on receipt of said fee he shall so record the same in a book especially prepared and kept for that purpose.

Appeal from board allowed. SEC. 27. Any party, or number of parties acting jointly, who may feel themselves aggrieved by the determination of the board of control, may have an appeal from the board of control to the district court of the judicial district within which the appropriation or appropriations of the party or parties so aggrieved may be situated. All persons joining in the appeal shall be joined as appellants, and all persons having interests adverse to the parties appealing, or either of them, shall be joined appellees.

Proceedings on appeal. SEC. 28. The party or parties appealing shall, within sixty days of the determination of the board of control, which is appealed from, and the entry thereof in the records of the board, file in the district court to which the appeal is taken, a notice in writing, stating that such party or parties appeals to such district court from the determination and order of the board of control; and upon the filing of such notice the appeal shall be deemed to have been taken: *Provided, however*, That the party or parties appealing shall, within the sixty days mentioned, enter into an undertaking, to be approved by the district court or judge thereof, and to be given to all the parties in the said suit or proceeding, other than the parties appealing, and to be in such an amount as the court or judge thereof shall fix, conditioned that the parties

[1] As amended, 1895.

giving their said undertaking shall prosecute their appeal to effect, and without unnecessary delay, and will pay all costs and damages which the party to whom the undertaking is given, or either or any of them, may sustain in consequence of such appeal.

Notice of appeal. SEC. 29.[1] The clerk of the district court shall immediately upon filing of said notice of appeal and the approval of the bond mentioned in section twenty-eight, transmit to the secretary of the board of control a notice over the seal of the court to the effect that said appeal has been perfected, which notice shall be entered of record by the secretary in the records of the board of control, and the appellant or appellants [shall] cause a certified copy thereof to be served on each of the appellees, serving the same in the manner provided for the serving of a summons in the district court.

Transcript and petition to be filed. SEC. 30.[1] The appellant or appellants shall within six months after the appeal, as provided for in sections twenty-seven, twenty-eight, and twenty-nine, is perfected, file in the office of the clerk of the district court a certified transcript of the order of determination made by the board of control, and which is appealed from, a certified copy of all the records of the board of control relating to such determination, and a certified copy of all the evidence offered before the board of control, including the measurements of streams, tributaries, and ditches, provided for by section twenty-four, together with the petition setting out the cause of complaint of the party or parties appealing, to which petition all parties joined as appellees shall be served with notice by the issuance of summons out of the office of the clerk of such district court within the time and manner provided by law for the issuance and service of summons in actions of law; and all proceedings of appeal shall be conducted according to the provisions of the civil code of procedure and the practice of appeals from the district courts of the State to the supreme court: *Provided*, That all hearings in the district court on appeal be had upon the evidence theretofore taken, and certified from the office of the board of control, and no new evidence shall be permitted, unless it shall appear by proper and satisfactory showing that new evidence has been discovered which could not with reasonable diligence have been discovered prior to the final hearing before the board.

It shall be the duty of the clerk of the district court immediately upon the entry of any judgment, order, or decree by the district court, or by the judge thereof, in an appeal from the decision of the board of control to transmit a certified copy of said judgment, order, or decree to the secretary of the State board of control. It shall be the duty of the secretary to immediately enter the same upon the records of such office, and the State engineer shall forthwith issue to the superintendent or superintendents of water divisions instructions in compliance with the said judgment, order, or decree, and in execution thereof. All costs made and accruing by reason of such appeal shall be adjudged to be paid by the party or parties against whom such appeal shall be finally determined.

During the time an appeal from order of the board of control is pending in the district court, and until a certified copy of the judgment, order, or decree of the district court is transmitted to the State engineer, the division of water from the stream involved in such appeal shall be made in accordance with the order of the board of control.

Proviso. *Provided*, That at any time after the appeal has been perfected the appellant or appellants may stay the operations of said decree appealed from by filing a bond in the district court, wherein such appeal is pending, in such amount as the judge thereof may designate, conditioned that he will pay all damages that may accrue to the appellee or appellees by reason of such order or decree not being enforced, should the proceedings and appeal be decided against the appellant. And immediately upon the filing and approval of such bond to stay the operations of the decree, the clerk of the district court shall transmit to the board of control a notice over the seal of the court to the effect that such bond has been filed, and that the operations of such decree are stayed during the pending of such appeal proceedings. This notice shall be recorded in the records of the board of control, and the State engineer shall immediately give proper notice to the superintendent of the water division wherein such appeal may have been taken.

Transfer of county records to engineer. SEC. 31. Within thirty days from the passage of this act it shall be the duty of the county clerk, in each of the counties of this State, to prepare a full and complete transcript of all the claims to appropriations of water now on file in their respective offices, and to transmit the same without delay to the State engi-

[1] As amended, 1895.

neer, by express or registered mail, for which service he shall be paid by the county the sum of four dollars per day for each and every day required to prepare said transcript: *Provided*, That the county clerk shall, in place of such abstract, transmit such original records of claims to water as are recorded in books kept specially for that purpose. It shall also be the duty of the clerk of the district court, within thirty days from the date of the passage of this act, to transmit to the State engineer, in like manner, the certificates of measurements of ditches made by county surveyors, now on file in the offices of said clerks of the district courts in the various counties of the State.

Engineer to file and classify.

SEC. 32. Immediately on receipt of said transcripts and said original records, it shall be the duty of the State engineer to file them in his office, and to classify and arrange said claims by placing all the claims to water of one stream and its tributaries together.

Who to be notified.

SEC. 33. In issuing notices to claimants, in priority adjudications of the waters of any stream and its tributaries, as provided in section twenty of this act, all parties named as claiming the waters of said stream or tributaries in said transcript shall be notified by mail, as specified in said section.

Application for right to appropriate water.

SEC. 34.[1] Any person, association, or corporation hereafter intending to acquire the right to the beneficial use of the public water of the State of Wyoming, shall, before commencing the construction, enlargement, or extension of any ditch, canal, or other distributing works, or performing any work in connection with said construction or proposed appropriation, make an application to the State engineer for a permit to make such appropriation. Such application must set forth the name and post-office address of the applicant; the source of the water supply; the nature of the proposed use; the location and descriptions of the proposed ditch, canal, or other work; the time within which it is proposed to begin construction; the time required for the completion of construction; and the time required for the complete application of the water to the proposed use.

In case the proposed right of use is for agricultural purposes, the application shall give the legal subdivisions of land proposed to be irrigated, with the total acreage to be reclaimed, as near as may be. On receipt of this application, which shall be of a form prescribed by the State engineer, it shall be the duty of that officer to make an indorsement thereon of the date of its receipt, and to make a record of such receipt in some suitable book in his office. It shall be his duty to examine said application and ascertain if it sets forth all the facts necessary to show the location, nature, and amount of the proposed use. If upon such examination the application is found defective, it shall be the duty of the State engineer to return the same for correction; the date of such return, with the reasons therefor, shall be indorsed on the application and a record made thereof in the book kept for recording receipts of such applications. A like record shall be kept of the date of the return of corrected applications and of the date of the refusal and return of applications rejected.

All applications which shall comply with the provisions of this act and with the regulations of the engineer's office, shall be recorded in a suitable book kept for that purpose; and it shall be the duty of the State engineer to approve all applications made in proper form, which contemplate the application of the water to a beneficial use and where the proposed use does not tend to impair the value of existing rights, or be otherwise detrimental to the public welfare. But where there is no unappropriated water in the proposed source of supply, or where the proposed use conflicts with existing rights, or threatens to prove detrimental to the public interest, it shall be the duty of the State engineer to reject such application and refuse to issue the permit asked for.

The refusal or approval of an application shall be indorsed thereon and a record made of such indorsement in the State engineer's office. The application so indorsed shall be returned to the applicant. If approved, the applicant shall be authorized, on receipt thereof, to proceed with the construction of the necessary works and to take all steps required to apply the water to a beneficial use and to perfect the proposed appropriation. If the application is refused, the applicant shall take no steps toward the prosecution of the proposed work, or the diversion and use of the public water, so long as such refusal shall continue in force.

Before either approving or rejecting an application, the State engineer may require such additional information as will enable him to properly guard the public interests, and may, in the case of applications proposing to divert more than

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[1] As amended, 1895.

twenty-five cubic feet of water per second of time, or to reclaim over one thousand acres of land, require a statement of the following facts:

In case of incorporated companies, he may require the submission of the articles of incorporation, the names and places of residence of its directors and officers, the amount of its authorized and of its paid-up capital.

If the applicant is not an incorporated company, he may require a showing as to the name or names of the party or parties proposing to construct the work, and a showing of facts necessary to enable him to determine whether or not they have the financial ability to carry out the proposed work, and whether or not the said application has been made in good faith.

In his indorsement of approval on any application, the State engineer shall require that actual construction work shall begin within one year from the date of such approval, and that the construction of any proposed irrigation work shall be completed within a period of five years from the date of such approval. He may limit the application to a less period of time for the completion of work than is asked for, and likewise the perfecting of the proposed right for a less period than named in the application. That the State engineer shall have authority, for good cause shown, to extend the time within which irrigation or other works shall be completed, and under any permit therefor issued by said engineer.

Any applicant feeling himself aggrieved by the indorsement made by the State engineer upon his application, may, in writing, in an informal manner, and without pleadings of any character, appeal to the board of control for an examination and reversal of the indorsement of the State engineer; and if he shall deem himself aggrieved by the order made by the board of control, with reference to his application, he may take an appeal therefrom to the district court of the county in which the point of diversion of the proposed appropriation shall be situated. Such appeal shall be taken within sixty days from the issuance of the order by the board of control, and shall be perfected when the applicant shall have filed in the office of the clerk of such district court a copy of the order appealed from, certified by the secretary of the board of control as a true copy, together with the petition to such court setting forth the appellant's reason for appeal. Such appeal shall be heard and determined upon such competent proof as shall be adduced by applicant, and such like proofs as shall be adduced by the board of control, or some person duly authorized in its behalf.

Map to be filed. SEC. 35.[1] Each application for permit to appropriate water for beneficial uses must be accompanied by a map or plat in duplicate showing accurately the location and extent of the proposed work.

These maps or plats must be drawn on tracing linen, on a scale not less than two inches to the mile; they must show the location of the head gate or point of diversion by courses and distances from some Government corner; they must show the actual location of the ditch or canal, or water line of the reservoir, and must show, wherever section lines are crossed, the distance to the nearest Government corner. The map or plat must show the course of the river, stream, or other source of supply, the location and area of all land proposed to be reclaimed, the position and area of all reservoirs or basins intended to be created for the purpose of storing water; the location of the intersection with all other canals, ditches, laterals, or reservoirs which are crossed by this work or with which connections are made; but all streams and all intersecting ditches, canals, and reservoirs not connected with the proposed work must be represented in ink of a different color from that used to represent the proposed work. These maps must contain the name of the proposed work, and, where possible, the number of the permit. They must, in addition, have the name or names of the applicant or applicants, and a certificate of the surveyor giving the date of survey, his name and post-office address.

It shall be the duty of the State engineer to examine these maps or plats and to ascertain if they agree with the description contained in the application, and when found to agree, or made to agree, to approve the same, file one copy in his office and return the other, approved, to the party filing them.

In case of ditches or canals carrying more than fifty cubic feet of water per second the engineer may require, in addition to maps or plats above described, the following:

A longitudinal profile of the ditch showing the bottom and proposed water line: the horizontal scale of this line shall not be less than one inch to one thousand feet, and the vertical scale not less than one inch to twenty feet.

A plan showing cross sections at a sufficient number of points to show all the different forms which the ditch when completed will take, and showing what

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[1] As amended, 1895.

portion of the water is to be conveyed in excavation, and what portion to be conveyed in fill. These plans shall be drawn on a horizontal and vertical scale of one inch to twenty feet.

Plans of any dams, cribs, embankments or other proposed works to obstruct any river, stream, lake or pond, or other source of water supply, shall be drawn on a longitudinal scale of not less than one inch to two hundred feet, and for cross sections on a scale of not less than one inch to twenty feet; and shall show what material is intended to be used and placed in such work. Timber, brush, stone or other material except earth used in such works shall be shown in detail on a plan, the scale of which shall not be less than one inch to four feet. The maps of all proposed reservoirs shall show the surface of the ground under water, and a sufficient number of lines of level shall be shown so that the contents of the reservoir or basin may be accurately determined. If the levels shall be shown by contour lines, they shall be on a scale sufficiently large to show vertical levels not exceeding five feet, and with all such reservoir plans there shall be furnished a plan, on a scale of not less than one inch to four feet, showing the method of providing a waste way for such reservoir and the method of drawing off the water from such reservoir or basin.

Certificate to appropriator. SEC. 36. Upon it being made to appear to the satisfaction of the board of control that any appropriation made in pursuance of the application of this act provided for has been perfected in accordance with such application, and the endorsement thereon by the State engineer, it shall be the duty of the board of control, by the hand of its president, attested under the seal of the secretary, to send to the county clerk certificate of the same character as that described in section twenty-six of this act, which said certificate shall be recorded in the office of the county clerk, as provided in section twenty-six of this act.

Date of priority. SEC. 37. The priority of such appropriation shall date from the filing of the application in the engineer's office.

Legal standard. SEC. 38. A cubic foot of water per second of time shall be the legal standard for the measurement of water in this State, both for the purpose of determining the flow of water in natural streams, and for the purpose of distributing water therefrom.

County to pay expense of printing. SEC. 39. All bills for the printing of notices to claimants of water in the adjudications provided for in this act shall be paid for by the county in which the stream, the appropriation of whose waters shall have been so adjudicated, shall be situated, the said bills to be approved by the superintendent of the water division in which the adjudication is made.

Districts. SEC. 40. The board of control shall divide the State into water districts, said water districts to be so constituted as to secure the best protection to the claimants for water, and the most economical supervision on the part of the State; said water districts shall not be created until a necessity therefor shall arise, but shall be created from time to time as the appropriations and priorities thereof, from the streams of the State, shall be adjudicated.

Commissioner, how appointed. SEC. 41. For each water district created under this act there shall be appointed one commissioner, who shall be a resident of the district in which he is to serve, and who shall be appointed by the governor, to be selected by him from persons recommended to him by the superintendent of the water division in which such water district is situated. Each commissioner shall hold his office two years and until his successor is appointed and has qualified, and the governor shall by like selection and appointment fill all vacancies which may occur in the office of water commissioner, and may at any time remove any water commissioner for failure to perform his duties as such water commissioner, upon complaint in that respect being made to him in writing.

Duties; penalty for interference; power to arrest. SEC. 42. It shall be the duty of said water commissioner to divide the water in the natural stream or streams of his district among the several ditches taking water therefrom, according to the prior rights of each, respectively, in whole or in part, and to shut and fasten, or cause to be shut and fastened, under the direction of the superintendent of his water division, the head gates of ditches heading in any of the natural streams of the district, when, in times of scarcity of water, it is necessary so to do by reason of the priority of rights of others taking water from the same stream, or its tributaries. Every person who shall wilfully open, close, change, or interfere with any head gate or water box without authority shall be deemed guilty of a misdemeanor, and on conviction thereof shall be fined a sum not exceeding one hundred dollars, or to be imprisoned in the county jail for a term not to exceed six months, or by both such fine and imprisonment.

The water commissioners or their assistants, within their districts, shall have power to arrest any person or persons offending, and turn them over to the sheriff of the proper county, and immediately upon delivering any such person, so arrested into the custody of the sheriff, it shall be the duty of the water commissioner making such arrest to immediately, in writing and upon oath, make complaint before the proper justice of the peace against the person so arrested.

Pay of. SEC. 43. Water commissioners herein provided for shall each be entitled to pay at the rate of five dollars per day for each day he shall be actively employed in the duties of his office, to be paid by the county in which the work is performed. Each water commissioner shall keep a just and true account of the time spent by him in the duties of his office, and the time spent by him in the performance of his duties in each county, respectively, into which his water district may extend, and shall present a true copy thereof, verified by oath, to the board of county commissioners of the county in which the work may have been done. And the said board of county commissioners shall, upon approval thereof by the superintendent of the water division, allow the same.

Assistants. SEC. 44. Said water commissioner shall have power, in case of emergency, to employ suitable assistants to aid him in the discharge of his duties. Such assistants shall take the same oaths as the water commissioner, and shall obey his instructions, and each shall be entitled to four dollars per day for every day he is employed, not to exceed thirty-five days in one year, to be paid upon certificates of the division superintendent, in the same manner as provided for the payment of the water commissioners.

When to begin work. SEC. 45. Said water commissioners shall not begin their work until they have been called upon by two or more owners or managers of ditches, or persons controlling ditches in the several districts, by application in writing, stating that there is a necessity for the use of water; and they shall not continue performing services after the necessity therefor shall cease.

Head gate; measuring flume; when not constructed. SEC. 46. The appropriator of any of the public waters of the State shall maintain, to the satisfaction of the division superintendent of the district in which such appropriation is made, a substantial head gate at the point where the water is diverted, which shall be of such construction that it can be locked and kept closed by the water commissioner; and such appropriator shall construct and maintain, when required by the division superintendent, a flume or measuring device, as near the head of such ditch as is practicable, for the purpose of assisting the water commissioner in determining the amount of water that may be diverted into said ditch from the stream. If any owner or appropriator of public waters that may have been adjudicated upon should neglect or refuse to put in such head gate, or measuring device, after thirty days' notice to do so by the division superintendent, the said superintendent may notify the county commissioners of the county where such head gate, flume, or measuring device is [should be] situated, and it shall be the duty of said county commissioners, when so notified by said division superintendent, to put in such head gate, flume, or measuring device at the expense of the county where the expense is incurred, and present a bill of costs to the owner or owners of the ditch, and if such owner or owners shall refuse or neglect, for three days after the presentation of such bill of costs, to pay the same, the said costs shall be made a charge upon the said ditch, and shall be collected as delinquent taxes, and be subject to the same conditions and penalties as other delinquent taxes, and until the full and complete payment of such bill of costs, it shall be the duty of the water commissioner of the district in which such ditch is situated to close and keep closed the head gate of such ditch, and to take such needful steps as will prevent any water from being diverted therein from the source of supply.

Pending cases, procedure in. SEC. 47. All cases relating to the adjudication of priorities of rights to the use of water for beneficial purposes, in any of the water districts of this State, now pending in any of the district courts of the State, excepting such cases which may have been, by any such courts by order, referred to the board of control may remain in said courts, and said courts shall proceed with the adjudication thereof in accordance with the laws in force at the time of the inception of such cases: *Provided*, That said court, or judge thereof in vacation, may, in its discretion, on the application of the parties interested, transfer any such case for adjudication to the board of control. All such cases which may have been, in the manner aforesaid, referred by any district court to the board of control shall, together with all the testimony heretofore taken in said cases, and with all the papers and pleadings relative thereto, and a copy of all journal *entries made in the case*, at once, on the passage of this act, be transferred by the

clerk of such district court into the custody of the division superintendent of the division in which said adjudication may have been begun, and said division superintendent shall, as soon as possible, complete the taking of such testimony, and it shall be the duty of the board of control to first determine the rights of the parties on those streams where such determination has begun, and is unfinished at the time of the passage of this act.

WATER-RIGHT FORMS USED IN WYOMING.

Application for a permit to divert and appropriate the water of the State of Wyoming.

Water division No. —. District No. —.

I, —— ——, of ——, county of ——, State of ——, being duly sworn according to law, upon my oath say:

1. The name of the applicant —— ——.
2. The post-office address of the applicant —.
3. The use to which the water is to be applied is —.
4. The name of the ditch or canal is —.
5. The source of the proposed appropriation is —.
6. The head gate of the proposed ditch or canal is located —— of section ——, township —, range —.
7. The said ditch or canal is to be — miles long and to pass through the following lands (give route by courses and distances, or by naming legal subdivisions crossed).
8. The dimensions of said works are: (*a*) [At head gate] width on top (at water line), feet; width on bottom, feet; depth of water, — feet; grade, —— feet per mile.

(*b*) Give diminsions at each point where reduced in size, stating miles from head gate.

[At —] width on top (at water line), — feet; width on bottom, feet; depth of water, feet; grade, — feet per mile.

[At —] width on top (at water line) feet; width on bottom, feet; depth of water, feet; grade, feet per mile.

[At —] width on top (at water line), — feet; width on bottom, feet; depth of water, — feet; grade, feet per mile.

9. Describe the character of proposed works, stating: First. The nature of material to be moved. Second. Number and length of tunnels, if any. Third. Amount of fluming, if any.
10. The estimated cost of said ditch is —— dollars.
11. The land to be irrigated has a total area of acres, described as follows: (Give estimated acreage in fractions of subdivisions.)
12. Construction will begin on proposed works on or before , 1——.
13. The time required for the completion of ditches and other distributing works is —— year from —, 1—.
14. The time required to complete the application of water to the beneficial use stated in this application is — year from —, 1 .
15. A map of the proposed ditch or canal, prepared in accordance with chapter 45, Session Laws of 1895, accompanies this application.

Signed: ——.

NOTE.—The statements in the foregoing application must comply with the requirements of chapter 45, Session Laws of 1895.

THE STATE OF WYOMING, *County of* —, *ss:*

I hereby certify that the foregoing application was signed in my presence and sworn to before me by —— —— this —— day of —, 1 .

—— ——.

THE STATE OF WYOMING, *State Engineer's Office, ss:*

This is to certify that I have examined the foregoing application and have returned the same without my approval for the following reasons: —.

Witness my hand this —— day of ——, A. D. 1——.

—— ——,
State Engineer.

THE STATE OF WYOMING, *State Engineer's Office, ss:*

This is to certify that I have examined the foregoing application and do hereby grant the same subject to the following limitations and conditions:

Construction of proposed work shall begin within one year from date of approval.

The time for completing the work shall terminate on December 31, 1——.

The time for completing the appropriation of water for beneficial use shall terminate on December 31, 1——.

The amount of the appropriation shall be limited to 1 cubic foot per second of time for each 70 acres of land reclaimed on or before December 31, 1——, and the additional volume used for ——— purposes on or before said date.

Witness my hand this —— day of ———, A. D. 1——.

——— ———,
State Engineer.

No. —.

Application for a permit to appropriate the water of the State of Wyoming.

Division No. ——. District No. ——.

THE STATE OF WYOMING, *State Engineer's Office, ss:*

This instrument was received and filed for record on the —— day of ———, A. D. 1——, at —— o'clock ——. m., and duly recorded in book —— of —— on page ——.

——— ———,
State Engineer.

Letter which accompanies blank form of proof of appropriation mailed to irrigators in advance of submission of testimony showing right to the beneficial use of water.

——— ———, 189—.

M ——— ———.

DEAR SIR: Your attention is called to the inclosed proof of appropriation. It is the intention of the law and also of the board of control to make the adjudication of rights to the use of water as inexpensive to the appropriator as possible. Consequently you are requested to cooperate with the division superintendent to whom you submit your testimony to the extent that you prepare yourself to answer all questions readily and accurately before the day set for submitting said testimony.

Your special attention is called to those questions whose answers indicate the date of your appropriation and use of the water, and to the acreage of land irrigated and description thereof.

By complying with this request you will not only facilitate the taking of testimony, but will insure the correct establishment of the respective rights and possibly prevent expensive and aggravating litigation.

Yours, truly,

——— ———,
Division Superintendent.

Proof of appropriation of water.

Permit No. ——.

(In accordance with the provisions of chapter 8, Session Laws of Wyoming, 1890-91, and amendment of 1895.)

From ——— ———. Division No. ——. District No. ——.

1. Q. State your name. A. ——— ———.
2. Q. Post-office address. A. ———.
3. Q. Are you the original applicant for permit No. ——? A. ———.
4. Q. If not, state the date of your securing an interest therein and the nature of your interest in the works constructed under such permit. A. ———.
5. Q. When did construction of the ——— ditch (or other distributing works described in said permit) begin? A. ———.
6. Q. When was it completed? A. ———.

7. Q. What are the dimensions of the ditch (or other distributing works) built under said permit? A. ———.

8. Q. Give the legal subdivisions of land owned or controlled by you on which water has been used, and if an appropriation of water for irrigation is claimed, give the acreage which has been irrigated in each legal subdivision. A. ———.

9. Give the date when, under the terms of this permit, water was first beneficially used. A. ———.

10. Q. If for irrigation, give the location and acreage irrigated the first year and the location and acreage irrigated each subsequent year to the present. A. ———.

11. Q. What crops were grown on this land in 189—? Give estimated acreage of each crop. A. ———.

12. Q. During what months is water beneficially used? A. ———.

13. Q. Give amount of your investment in the construction of ditch and laterals. A. ———.

14. Q. Give estimated cost per acre of preparing land for irrigation. A. ———.

15. Q. Does the map which accompanies this proof show correctly the size and location of diverting works and area of land where water was used? A. ———.

THE STATE OF WYOMING, *County of* ———, *ss:*

I, ——— ———, being first duly sworn, do depose and say that I have read the above and foregoing proof of appropriation of water; that I know the contents thereof, and that the facts therein stated are true.

In witness whereof I have hereunto set my hand this —— day of ———, A. D. 189—.

——— ———.

———, Wyo., ———, 189—.

I hereby certify that the foregoing affidavit was read to the affiant in my presence before he signed his name thereto; that said affiant is to me personally known (or has been satisfactorily identified before me by ——— ———), and that I verily believe him to be a credible person and the person he represents himself to be; and that this affidavit was subscribed and sworn to before me at ——— on this —— day of ———, 189—.

——— ———.

NOTE.—This proof is intended to be used only by parties making appropriations under permits issued in accordance with chapter 8, Session Laws 1890-91.

The map referred to in paragraph 15 must show the entire work in the case of individual ditches. In the case of larger works only one map of the entire canal need be filed. Individual proof must, however, show ditch from point of diversion from main canal and all laterals on land reclaimed. Where the duplicate map filed in the State engineer's office and returned to the applicant gives necessary details and shows accurately the location of completed work, it may be filed.

This proof should be carefully verified and acknowledged before a person authorized to administer oaths.

The map which accompanies this proof must be on tracing linen, be accurately drawn on a scale not less than 2 inches to the mile, and verified by the party making the measurements.

Application No. —. ——— ditch. Taking water from ———. Water division No. ——, in ——— County.

I, ——— ———, do hereby certify that after giving notice to ——— ———, the applicant for certificate of appropriation of water, in accordance with the conditions of the above-named permit, I made on ——— an examination of the above-named ditch and of the lands for which an appropriation is claimed.

A measurement of the ditch at ——— gave the following dimensions:

Width on bottom, —— feet; width at surface of water, —— feet; depth, —— feet.

I found the ditch (here state, if the ditch is carrying water, the depth and velocity of flow; if not carrying water, the depth of water it has carried).

I would further report that I visited and personally examined each legal subdivision of land for which an appropriation is claimed, and found that the following acreage has been irrigated in each 40-acre tract: ———.

On this land the following crops were grown in 189—: ——— acres ———.

I found —— laterals which showed evidence of use, and that they are large enough and so located as to fully irrigate and reclaim the land above described.

I recommend that a certificate of appropriation be issued for the lands reclaimed.

——— ———.

Report of official examiner.

I hereby certify that an official inspection and measurement of the —— and of the lands described in the foregoing proof of appropriation of water was made by —— —— on the —— day of ——, 189—, and that the results of such inspection are given in the foregoing report. In accordance therewith I hereby submit the following recommendation: ——.

—— ——,
Superintendent Water Division No.—.

Proof of appropriation under permit No.—

Division No. —. District No. —. From —— ——. Name of appropriator, ——.

Filed with me this —— day of ——, 189—.

—— ——,
Superintendent.

Filed in this office this —— day of ——, 189—.

—— ——,
President Board of Control.

STATE OF WYOMING.

Proof of the appropriation of water.

From —— ——, Division No. ——. State your name, ——.

1. Q. Post-office. A. ——.
2. Q. State the use to which the water has been applied. A. ——.
3. Q. State the means of diversion employed. A. ——.
4. Q. If through a ditch, state its name. A. ——.
5. Q. (*a*) State the date of the survey of the ditch or other distributing works through which the water claimed is diverted. (*b*) The date when the construction of such ditch was begun and when completed. A. (*a*) ——. (*b*) ——.
6. Q. If any enlargements were made, state the date when begun and the date when completed. A. ——.
7. Q. State the dimensions of the ditch as originally constructed, and as enlarged, and, if measured by the county surveyor under the provisions of the act of 1886, give the results of such measurements. A. ——.
8. Q. State the name of person, association of persons, or corporation who built the ditch or canal, and the name or names of its present owners. A. ——.
9. Q. If water is claimed for irrigation, give the legal subdivisions of land owned or controlled by you for which an appropriation is claimed. A. ——.
10. Q. State the nature of your title to the above-described land, and if not owned by you give the name of the owner and the nature of the possessory right which you exercise. A. ——.
11. Q. State the year when water was first used for irrigation or other beneficial purposes, and by whom. A. ——.
12. Q. If for irrigation, give the number of acres watered the first year, giving the legal subdivisions on which used and, as near as may be, the acres irrigated in each subdivision. A. ——.
13. Q. State the number of acres watered each subsequent year, and give the legal subdivisions on which the water was used, and as near as may be the acres irrigated in each legal subdivision. A. ——.
14. Q. State the number of acres irrigated from said ditch in 189—, and give the legal subdivisions on which water was used, and as near as may be the acres irrigated in each subdivision. A. ——.
15. Q. State the acreage said ditch is capable of watering, give the legal subdivisions of land which it can be made to irrigate, and state who owns said land. A. ——.
16. Q. State your proportionate interest in said ditch. A. ——.

(16) The plat prepared by the State engineer is hereby accepted as showing correctly the location of the —— ditch and the land which can be irrigated therefrom.[1] A. ——.

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[1] In case there is objection to the official plat the parties objecting must, when giving proof, file a written statement of the reasons therefor, and must within thirty days file with the division superintendent a map of said ditch and irrigated lands, with affidavit of surveyor, giving date of survey, attached thereto.

17. Q. When does your irrigation season begin and when does it end? A. ——.
18. Q. If water is used for other purposes than irrigation, state the nature of such use and the time when such use began. A. ——.
19. Q. How much water is required for such purpose? A. ——.
20. Q. During what months is the water used? A. ——.
21. Q. Have you or any other claimant of said appropriation filed a claim to water in the office of the county clerk? If so, give date of filing and the name of the party or parties interested in said claim. A. ——.
22. Q. Have you had sufficient water each year since the use for which an appropriation is claimed began? A. ——.
23. Q. If not, state the years of scarcity, the months when the supply was insufficient, and the reason of such scarcity. A. ——.

Remarks: —— ——.

Signed: —— ——.

——, Wyo., ——, 189—.

I hereby certify that the foregoing affidavit was read to the affiant in my presence before he signed his name thereto; that said affiant is to me personally known (or has been satisfactorily identified before me by —— ——), and that I verily believe him to be a credible person and the person he represents himself to be; and that this affidavit was subscribed and sworn to before me at —— on this —— day of ——, 189—.

—— ——,
Division Superintendent.

Division No. — District No. —. From — . Name of claimant, —— ——.

Filed with me this — day of — , 189 —.

—— ——,
Superintendent.

Filed in this office this — day of — , 189— .

—— ——,
President Board of Control.

THE STATE OF WYOMING.

Certificate of appropriation of water.

Whereas ——, of —— County, Wyoming, has presented to the board of control of the State of Wyoming proof of the appropriation of water from —— through the —— for — .

Now know ye, that the board of control, under the provisions of chapter 8 of the Session Laws of 1890–91, entitled "An act providing for the supervision and use of the waters of the State," approved December 22, 1890, has, by an order dated the —— day of — — , A. D. 189 —, determined and established the priority and amount of appropriation as follows: Name of appropriator, ; post-office address, ——; number of general priority, — ; first appropriation, ——; number of priority on ——; first appropriation, ; amount of first appropriation, —— cubic feet per second; date of first appropriation, ——; description of land to be irrigated, ——.

In testimony whereof I, —— —, president of the State board of control, have hereunto set my hand this — — day of — — , A. D. 189 —, and caused the seal of said board to be hereunto affixed.

[SEAL.]

——,
President.

Attest:

—— ——,
Secretary.

WATER LAWS OF NORTHWEST TERRITORIES OF CANADA.

61 Victoria, Chapter 35.

AN ACT to amend and consolidate the northwest irrigation acts of 1894 and 1895. [Assented to 13th June, 1898.]

Her Majesty, by and with the advice and consent of the Senate and House of Commons of Canada, enacts as follows:

Short title. **1.** This act may be cited as the Northwest Irrigation Act, 1898.

Interpretation. **2.** In this act, unless the context otherwise requires—

Minister. (*a*) The expression "minister" means the minister of the interior;

Department. (*b*) The expression "department" means the department of the interior at Ottawa;

Commissioner. (*c*) The expression "commissioner" means the commissioner of public works for the Northwest Territories;

Chief engineer. (*d*) The expression "chief engineer" means the chief engineer and surveyor of the department of the public works for the Northwest Territories;

Dominion land surveyor. (*e*) The expression "Dominion land surveyor" means a surveyor duly authorized, under the provisions of the Dominion lands act, to survey Dominion lands.

Company. (*f*) The expression "company" means any incorporated company, the object and powers of which extend to or include the construction or operation of irrigation or other works under this act, or the carrying on thereunder of the business of the supply or the sale of water for irrigation or other purposes, and includes any person who has been authorized or has applied for authority to construct or operate such works or carry on such business, or who has obtained a license under section 11 of this act, and also includes any irrigation district incorporated under an ordinance of the Northwest Territories;

Works. (*g*) The exprestion "works" means and includes any dykes, dams, weirs, flood gates, breakwaters, drains, ditches, basins, reservoirs, canals, tunnels, bridges, culverts, cribs, embankments, headworks, flumes, aqueducts, pipes, pumps, and any contrivance for carrying or conducting water or other works which are authorized to be constructed under the provisions of this act;

Duty of water. (*h*) The expression "duty of water" means the area of land that a unit of water will irrigate, which unit is the discharge of one cubic foot per second;

Licensee. (*i*) The expression "licensee" means any person or company who is granted a license in accordance with the provisions of this act.

Application. **3.** This act shall apply to the Northwest Territories, except the provisional districts of Yukon, Mackenzie, Franklin, and Ungava.

Right to use waters. **4.** The property in and the right to the use of all the water at any time in any river, stream, water course, lake, creek, ravine, cañon, lagoon, swamp, marsh, or other body of water shall, for the purposes of this act, be deemed to be vested in the Crown, unless and until and except only so far as some right therein, or to the use thereof, inconsistent with the right of the Crown, and which is not a public right or a right common to the public, is established, and, save in the exercise of any legal right existing at the time of such diversion or use, no person shall divert or use any water from any river, stream, water course, lake, creek, ravine, cañon, lagoon, swamp, marsh, or other body of water, otherwise than under the provisions of this act.

Rights of grantee of Crown lands. **5.** Except in pursuance of some agreement or undertaking existing at the time of the passing of this act, no grant shall be hereafter made by the Crown of lands or of any estate, in such terms as to vest in the grantee any exclusive or other property or interest in or any exclusive right or privilege with

respect to any lake, river, stream, or other body of water, or in or with respect to the water contained or flowing therein, or the land forming the bed or shore thereof.

Right to use waters may be acquired only under this act.

6. After the passing of this act, no right to the permanent diversion or to the exclusive use of the water in any river, stream, water course, lake, creek, ravine, cañon, lagoon, swamp, marsh, or other body of water, shall be acquired by any riparian owner or any other person by length of use or otherwise than as it may be acquired or conferred under the provisions of this act, unless it is acquired by a grant made in pursuance of some agreement or undertaking existing at the time of the passing of this act.

Persons already holding a right must obtain license.

7. Every company or person who holds water rights of a class similar to those which may be acquired under this act, or who, with or without authority, has constructed or is operating works for the utilization of water, shall obtain a license under this act before the first day of July, one thousand eight hundred and ninety-eight.

If license is not obtained within stated time.

2. If such license is obtained within the time limited, the exercise of such rights may thereafter be continued, and such works may be carried on under the provisions of this act; otherwise such rights or works, and all the interest of such person therein, shall, without any demand or proceeding, be absolutely forfeited to Her Majesty, and may be disposed of or dealt with as the governor in council sees fit.

Application for license.

3. Except in case of applications for water for domestic purposes, as hereinafter provided, the applications for such license shall be made in the same manner as for other licenses under this act, and the like proceedings shall be had thereon and like information furnished in connection therewith.

Application for water rights which are vested in the Crown.

8. Any water the property in which is vested in the Crown may be acquired, for domestic, irrigation, or other purposes, upon application therefor as hereinafter provided; and all applications made in accordance with the provisions of this act shall have precedence, except applications under section seven, according to the date of filing them with the commissioner.

Water rights classified.

2. The purposes for which the right to water may be acquired are of three classes, namely: First, domestic purposes, which shall be taken to mean household and sanitary purposes and the watering of stock, and all purposes connected with the working of railways or factories by steam, but shall not include the sale or barter of water for such purposes; second, irrigation purposes; and, third, other purposes.

Rights of riparian proprietors.

9. No application for any purpose shall be granted where the proposed use of the water would deprive any person owning lands adjoining the river, stream, lake, or other source of supply of whatever water he requires for domestic purposes.

Preliminary work by licensee.

10. Any person contemplating or projecting any works under this act, may, upon submitting a general description of such works and upon payment of a fee of three dollars, obtain from the chief engineer a license to do the necessary preliminary work in connection with the location of such works; and after he obtains such license he may, with such assistants as are necessary, enter into and upon any public or private lands to take levels, make surveys, and do other necessary work in connection with such location, doing no unnecessary damage.

Entering lands.

Form of application.

11. Every applicant for license under this act, except as hereinafter provided, shall file with the commissioner the following documents:

Memorial.

(*a*) A memorial, in duplicate, on forms provided by the commissioner, in which the applicant shall set forth his name, residence, and occupation, his financial standing, the source from which water is to be diverted, the point of diversion, the probable quantity of water to be used, the size and character of the works to be constructed, the area and location of the land to be irrigated, the value of such land in its present state, including improvements, the probable number of consumers, and the rate, if any, to be charged for water sold; but if the applicant is an incorporated company, the memorial shall also set forth the names of its directors and officers and their places of residence, the date of its incorporation, the amount of the company's subscribed capital, the amount of its paid-up capital, the proposed method of

If applicant is an incorporated company.

raising further funds, if needed, and the purposes for which the company is incorporated;

Application to cross road allowance or surveyed road: general plan.

(b) An application, on forms provided by the commissioner, for the right to construct any canal, ditch, reservoir, or other works referred to in the memorial, across any road allowance or surveyed public highway, which may be affected by such works;

(c) A general plan, in duplicate, on tracing linen, drawn to a scale of not less than one inch to a mile, showing the source of supply, the position of the point of intake, the location of the main canals or ditches, the tract of land to be irrigated, the name of the owner of each parcel of land crossed by the canal, or ditch, or by any reservoir or other works connected therewith, or to be irrigated therefrom, and the position and area of all ponds, reservoirs, and basins intended to be constructed for the storage of water, and

Detail plan.

(d) A plan, in duplicate, on tracing linen, showing in detail all head works, dams, flumes, bridges, culverts, or other structures to be erected in connection with the proposed undertaking.

Additional plans in the case of certain canals.

12. In the case of all ditches or canals carrying more than twenty-five cubic feet of water per second, in addition to the above information, the applicants shall furnish the following maps or plans, in duplicate.

(a) A longitudinal profile of the ditch, showing the bottom and the proposed service water line, the horizontal scale being not less than one inch to four hundred feet, and the vertical scale not less than one inch to twenty feet;

(b) A plan showing cross sections at a sufficient number of points to fully illustrate all the different forms which the ditch when constructed will take, particularly on side hills or elsewhere where any portion of the water is to be conveyed in fill. When water is to be conveyed in cut there shall also be shown on this plan cross sections at points where the shortest horizontal distance from either side of the bottom of the ditch to the surface of the ground is less than double the bottom width of the ditch at that point. This plan shall be drawn on a horizontal and vertical scale of one inch to twenty feet.

Plans of works in connection with reservoirs.

(c) Plans of any dams, cribs, embankments, or other works proposed to obstruct any river, stream, lake, or other source of water supply, or in order to create a pond, reservoir, or basin of water anywhere, or which may have that effect, prepared on a longitudinal scale of not less than one inch to one hundred feet, and for cross sections on a scale of not less than one inch to twenty feet, and showing what material is intended to be used and how placed in such works. The timber, brush, stone, brick, or other material used in such works shall be shown in detail to a scale of not less than one inch to four feet;

Plans of grounds under reservoirs.

(d) Cross-section maps or plans showing the surface of the ground under such pond, reservoir, or basin of water and also the surface of the water proposed to be held therein; the horizontal scale of the said maps or plans shall be not less than one inch to one hundred feet, and the vertical scale shall be not less than one inch to twenty feet, and a sufficient number of lines of levels shall be shown, so that the contents of the pond, reservoir, or basin of water may be accurately determined. If the maps or plans show the levels by contour lines, they shall be on a scale sufficiently large that the contour lines shall show a vertical distance between them not exceeding one foot. The maps or plans shall have sufficient information to show clearly the property likely to be affected by the creation of such ponds, reservoirs, or basins of water, and the manner in which affected, and shall show in detail, on a scale of not less than one inch to four feet, the proposed manner of controlling and drawing off the water from any such pond, reservoir, or basin.

Memorials and plans to be open for inspection.

13. The memorials and plans filed as above prescribed, or a true copy thereof shall be open for examination by the public at all times in the department and at the office of the commissioner at Regina.

Filing elsewhere.

14. In any case in which he thinks proper, the minister may direct that a copy of the memorial and plans shall be filed in such other place or with such other official or person as he names for that purpose, and such copy also shall be open to public inspection.

Public notice of application.

15. Public notice of the filing of the memorial and plans shall forthwith be given by the applicant in some newspaper published in the neighborhood, to be named by the commissioner, not less than once a week for a period of thirty days, within which time all protests against granting the rights applied for shall

be forwarded to the minister, and such notice shall contain a statement of the nature of the rights applied for, and the general character and location of the proposed works.

Protests to be considered by minister.

2. The minister, after considering all protests filed, may authorize, as hereinafter provided, the construction of the proposed works, with such changes or variations as he deems necessary.

Memorial and plans to be examined and approved.

16. The memorial and plans filed with the commissioner, as herein provided, shall be examined by the chief engineer, and, after having been approved by him, one copy shall be forwarded for record purposes in the department; and upon receipt of such memorial and plans, properly approved, together with a certificate that the proper notice of the filing of such memorial and plans has been published, and that permission has been granted by the commissioner to construct such works across road allowances or surveyed public roads affected thereby, the minister may authorize the construction of the proposed works, fixing in such authorization a term within which the construction of the works is to be completed.

Changes in plans to be filed.

2. Any changes and variations ordered by the minister regarding the plans of the proposed works must be filed by the applicant in the office of the commissioner, and shall form a portion of the record open for public inspection.

Deviation from plans.

3. No material deviation from the plans filed shall be made without permission, and any question arising as to whether any deviation is material or otherwise shall be decided by the chief engineer, or such other officer as the minister designates.

Filing of plans may be waived in certain cases.

17. In the case of applications for water for domestic or irrigation purposes the minister may, if he sees fit, waive the necessity for filing the plans required by section eleven of this act, and may require the applicants to file a memorial only; but he may order that such memorial shall contain all the information necessary to a full and complete understanding of the rights applied for.

Inspection of works.

18. Any works authorized under this act shall, if the minister so determines, be constructed, subject to inspection during construction by the chief engineer, or any other officer to be named by the minister; and the cost of such inspection, or such portion thereof as the minister decides, shall be borne by the person or company constructing such works.

Inspection on application of proprietor near works.

2. Should any person residing on or owning land in the neighborhood of any works, either completed or in course of construction, apply to the minister in writing, desiring an inspection of such works, the minister may order an inspection thereof.

Deposit to be made by applicant.

3. The minister may require the applicant for inspection to make a deposit of such sum of money as the minister thinks necessary to pay the expenses of an inspection, and in case the application appears to him not to have been justified may cause the whole or part of the expenses to be paid out of such deposit.

Enforcing payment of costs.

4. In case the application appears to the minister to have been justified, he may order the person or company to pay the whole or any part of the expenses of the inspection, and such payment may be enforced as a debt due to Her Majesty.

Works to be made secure.

5. Upon any inspection under the provisions of this section the minister may order the person or company to make any addition or alteration which he considers necessary for their security to or in any works of the person or company, and noncompliance with such order may be dealt with in the same manner as is provided with respect to an order of the minister under section forty of this act.

6. Provided, that where under section seventeen the minister waives the necessity for plans this section shall not apply.

When work may be commenced.

19. The person or company, immediately after the receipt of the authorization, may proceed with the construction of the works authorized, and for the purposes of such construction shall have the powers conferred by the railway act upon railway companies, so far as the same are applicable to the undertaking of the person or company and are not inconsistent with the provisions of this act or with the authority given to the person or company, the provisions conferring such powers being

Powers under c. 29 of 1888.

taken for this purpose to refer to any work of the person or company where in the said act they refer to the railway.

Time for commencing works limited.

20. The construction of any work authorized under this act shall be commenced not later than two months after the date of the authorization, unless such two months expire between the first day of November and the first day of May following, in which case the time of commencement shall not be later than the first day of May following, and shall proceed continuously until sufficiently completed to supply water to all applicants within the area described in the authorization, provided there is sufficient water available for that purpose; and the minister or such officer as he designates shall be the sole arbiter as to whether the work is being prosecuted with sufficient vigor.

Extension of time in case of disaster.

2. Should any unforeseen disaster intervene to prevent the construction or completion of the works within the time limited, or for any other reasons which he deems sufficient, the minister may authorize an extension of time for the commencement or completion of the works.

Forfeiture of right if works are not completed within time limited.

3. Upon the expiration of the time limited for the completion of the works, the rights granted to the person or company shall cease and determine, except in so far as they are necessary for effectually operating the works then completed; and any works at the date of such forfeiture constructed or acquired may be taken over and operated or disposed of by the minister in the manner and upon the terms hereinafter provided.

Inspection of works on completion and issue of certificate for license.

24. Upon the expiration of the time mentioned in the authorization for the construction of any works, or at any time before such date, if the construction is sooner completed, an inspection shall be made by the chief engineer or such other officer as the minister appoints; and a certificate shall be issued by the chief engineer and be forwarded to the department setting forth that the works have been completed in accordance with the application, that the right of way for the works has been obtained, that agreements have been entered into for the supply of water for the irrigation of lands which are not the property of the applicant, and that the works as constructed are capable of carrying and utilizing a stated quantity of water.

License.

2. Upon receipt of such certificate the minister shall issue a license to the applicant for the quantity of water to which he is entitled, and such license shall be recorded in the office of the commissioner at Regina.

Priority of right.

25. Licensees shall have priority among themselves according to the number of their licenses, so that each licensee shall be entitled to receive the whole of the supply to which his license entitles him before any licensee whose license is of a higher number has any claim to a supply;

Settlement of disputes.

and if a complaint is made to the minister, or to an officer authorized by him to receive such complaints, that any licensee is receiving water from a source of supply to which another licensee is entitled by virtue of priority of right, and that the licensee having such priority of right is not receiving the supply to which he is entitled, some officer, to be named by the minister or the officer to whom complaint is so made, as the case may be, shall inquire into the circumstances of the case, and, if he finds that there is ground for the complaint, shall cause the head gates of the ditch or other works of the licensee who is receiving an undue supply of water to be closed, so that the supply to which the other licensee is entitled shall pass and flow to his works.

Licensee's rights limited by capacity of works.

26. When any works for carrying water are not of sufficient capacity to carry the quantity of water acquired by their owner, his exclusive right shall be limited to the quantity which such ditch, flume, or other contrivance is capable of carrying; and in case of dispute as to such quantity the minister may order an inspection of the works; and the report and finding of the inspecting officer as to the capacity thereof shall, for the purpose of this section, be final and conclusive.

Cancellation of license and reservation of water right in certain cases.

27. When the land to be irrigated by the water granted to a licensee is land for which letters patent from the Crown have not been issued, being held by the licensee under a homestead or other conditional entry or a lease in accordance with the provisions of the Dominion land act, or under an agreement to purchase such land, the license for such water shall be canceled upon receipt by the minister of a certificate of the cancellation of

such homestead or other conditional entry, lease, or sale agreement; but the water right necessary for the irrigation of such land may be reserved for such time as the minister determines, and may be disposed of, together with all works connected therewith, to the next occupant or purchaser of such land, upon such terms and conditions as the minister determines; and the new license issued for such water shall have the same number and hold the same priority of right as the original or canceled license.

Information to be afforded to inspecting engineer.

28. Every person and every company and the officers and directors thereof shall afford to any inspecting officer such information as is within their knowledge and power in all matters inquired into by him, and shall submit to such inspecting officer all plans, specifications, drawings, and documents relating to the construction, repair, or state of repairs of the works or any portion thereof.

Proof of his authority.

2. The production of instructions in writing signed by the minister or his deputy or the secretary of the department of the interior shall be sufficient evidence of the authority of such inspecting officer.

Penalty for obstructing him.

29. Every person who willfully obstructs an inspecting officer in the execution of his duty shall be liable, on summary conviction, to a penalty not exceeding twenty dollars, or to imprisonment for a term not exceeding two months, with or without hard labor, or to both.

Penalty for improper diversion by any person.

31. Every person who willfully, without authority, takes or diverts any water from any river, stream, lake, or other waters, or from any works authorized under this act, or who takes or diverts therefrom any greater quantity of water than he is entitled to, is guilty of an offence, and liable, upon summary conviction, to a fine not exceeding five dollars per day or fraction of a day for each unit or fraction of a unit of water improperly diverted, or to imprisonment for a term not exceeding thirty days, or to both, and upon indictment to a fine not exceeding five dollars per day or fraction of a day for each unit or fraction of a unit of water improperly diverted, or to imprisonment for a term not exceeding thirty days, or to both.

Penalty for improper diversion of water.

32. No licensee shall divert more water than the quantity actually granted by his license, and any licensee so doing shall be guilty of an offence punishable on summary conviction by a fine not exceeding five dollars per day or fraction of a day for each unit or fraction of a unit of water so diverted.

Disputes as to quantity of water diverted.

2. In case of dispute as to the quantity of water diverted, the minister may order an inspection of the works of the licensee by an officer named by him for that purpose and for the purposes of this section; the report and finding of such officer as to the quantity diverted shall be final and conclusive.

Forfeiture of licensee's rights by waste or nonuser.

33. When any licensee abandons or ceases to use or wastes any waters to which his license entitles him, and any charge of such abandonment or ceasing to use or wasting waste water is made to the minister, such charge may be inquired into by him or by any person or officer appointed by him for that purpose; and the minister, if he deems just and proper, may by order declare a forfeiture of the license, and the license so ordered or declared to be forfeited shall be canceled and shall cease and determine.

Disposal of surplus water to applicants.

34. Any licensee shall dispose of any surplus water flowing in his works which is not being utilized or used for the purposes authorized to any person applying therefor for irrigation purposes and tendering payment for one month in advance at the regular prices.

Payment by applicant.

2. Persons so applying shall pay an amount equal to the cost and expense of the works required to convey the surplus water to them, or shall themselves construct such works; and until this is done the delivery of surplus water need not be made.

Quantity of water to which applicant is entitled.

3. When the necessary works have been constructed and the payment or tender herein provided for has been made, the applicant shall be entitled to the use of so much of the surplus water as such works have the capacity to carry.

Limitation.

4. Nothing in this section shall be construed to give to any person acquiring the right to use surplus water any right to said surplus *water when* it is needed by the licensee for the purposes authorized, or to waste

or sell or dispose thereof after being used by him, or shall prevent the original owners from retaking, selling, or disposing thereof in the usual or customary manner after it has been so used as aforesaid.

No discrimination in prices after stated time. **35.** No licensee undertaking to sell water conveyed by his works shall, subsequent to the first four years after the construction of such works as are necessary to convey the water to the user, discriminate between the users of such water regarding the price thereof.

If supply of water is insufficient. 2. If from any cause the whole amount of water agreed to be supplied by a licensee is not available, then each user shall have furnished to him by the licensee so much water as shall bear to the available water the same proportion as his usual supply bears to the whole amount agreed to be furnished.

Penalty. 3. Any licensee violating these provisions shall be guilty of an offence against this act and liable upon summary conviction to a fine not exceeding one thousand dollars for each and every such offence, or to imprisonment for a period not exceeding two months, or to both.

Storage of water. **36.** The minister may grant to any licensee the right to store for irrigation purposes during periods of floods or high water, or during those portions of the year when water is not required for irrigation purposes, any water not being used during such periods.

Utilization for the purpose of existing works. 2. Should there be any works for the carriage of water which are not being utilized to their full capacity by their owner, and which can with advantage be utilized to carry the whole or any portion of the water desired to be stored any portion of the distance it is required to be so carried or conducted, without interfering with the use made of the said works by their owner, then the said works shall be placed at the disposal of the company desiring to so use it; and if the parties can not agree to the compensation to be paid for such service, the minister may fix the rate to be paid therefor.

Highway crossings. **37.** Any person or company constructing any works under the provisions of this act shall, during such construction, keep open for safe and convenient travel all public highways theretofore publicly traveled as such, when they are crossed by such works, and shall, before water is diverted into, conveyed or stored by any such works extending into or crossing any such highway, construct, to the satisfaction of the minister, a substantial bridge, not less than fourteen feet in breadth, with proper and sufficient approaches thereto, over such works; and every such bridge and the approaches thereto shall be always thereafter maintained by such person or company.

Unit of measurement. **38.** Under this act the discharge of one cubic foot of water per second shall be the unit of measurement of flowing water, and the cubic foot or acre-foot the unit of measurement of quantity. The acre-foot is equivalent to forty-three thousand five hundred and sixty cubic feet.

Annual return by company. **39.** Companies obtaining a license under this act shall, on or before the thirty-first day of January in each year, make a return to the minister, attested by the oath of its president and secretary, for the year ending the thirty-first day of December preceding, showing:

The amount expended on construction;
The amount expended on repairs;
The amount received from shareholders;
The amount of bonds issued;
The amount received for water supplied for irrigation;
The amount received from other sources;
The amount of dividend declared and paid;
The amount of capital stock authorized;
The amount of capital stock subscribed;
The amount of capital stock paid up to date;
The amount of bonded indebtedness;
The amount bonds sold for;
The rate of interest bonds bear;
The amount of indebtedness other than bonds, and the rate of interest such indebtedness is bearing;
The cost of management;
A statement of the works, and their extent and character;
The number of miles of canals, ditches, etc.;
The number of users;

The number of acres actually under irrigation;
The number of acres of irrigable land in the system;
The names of officers and employees;
The proposed extensions during ensuing years and the acreage to be covered thereby;
Such other data as the governor in council sees fit to order.

Copy of by-laws. 2 Attached to such annual return shall be a copy of the by-laws of the company, showing all amendments thereto during the year covered by the said return.

Exception. 3. The returns required by this section may be waived by the minister in the case of a private person supplying water solely to himself.

Order by minister in case of complaint against licensee. **40.** When a complaint, under oath of the complainant and of at least one witness, is made to the minister or the commissioner by a consumer of water who has paid his rates, that a licensee who has engaged or is under obligation to supply him with water is failing to do so, or is failing to keep his works in proper condition, the minister or some person or officer appointed by him for the purpose may make immediate inquiry and take all necessary steps to ascertain the truth of the complaint, and, if he considers the complaint established, may order and direct that the licensee shall take forthwith such action as he considers necessary in order as far as possible to remove the cause of complaint.

Reference to judge. 2. If the licensee fails to obey such order, the minister shall forthwith issue a certificate to that effect, reciting all the facts, which certificate being presented to the judge of the supreme court for the judicial district within which such works lie, the judge shall hear and determine the matter in a summary manner, and shall order the licensee to proceed with all dispatch to take such measures as he considers necessary in the premises; and **Refusal to obey order of judge.** refusal or neglect to obey any order made by a judge under this section may be treated and punished as contempt of court, and such other proceedings may be had and taken thereon as in the case of noncompliance with any other mandatory order of the said court or a judge thereof.

Amalgamation of companies. **41.** The governor in council may authorize two or more companies, whose works are contiguous, to unite and form one company, with a view to providing increased water supply and extending their works, when he is satisfied that the holders of more than fifty per cent of the capital stock of each company are in favor of the union, that users dependent upon the water supply will not be injured, and that the companies to be united have the necessary financial means for carrying out the proposed undertaking, the same particulars being furnished to the governor in council as are required to be furnished upon an application for authorization to construct works under this act; and public notice of the authorization of the united companies and their proposed works shall be given in the manner prescribed in the case of an application under section fifteen.

Minister may issue summons. **42.** The minister or any one specially authorized by him may, when he deems it necessary for the satisfactory carrying out of the provisions of this act or the regulations to be framed under it, summon before him any person by subpœna, examine such person under oath, and compel the production of papers and writings; and for **Penalty for disobeying it.** neglect to obey such summons or refusal to give evidence, or to produce the papers or writings demanded of him, the minister or the person authorized may, by warrant under his hand, order the person in default to be imprisoned in the nearest common jail as for contempt of court, for a period not exceeding fourteen days.

Before whom affidavits may be taken. **43.** All affidavits, oaths, solemn declarations, or affirmations required to be taken under this act or any regulations made thereunder, may be taken before any agent authorized under this act, a Dominion lands agent or officer, or any persons specially authorized by the minister to take them, or any other persons authorized to take affidavits in the Northwest Territories; and the minister may require any statement called for under this act, or under any such regulation, to be verified by oath, affidavit, affirmation, or declaration.

Minister may order surveys, etc. **44.** The minister may take such steps as he deems necessary at any time to secure a complete or partial survey of the sources of the water supply for irrigation and other purposes, with an estimate of the extent and location of *irrigable lands*, and of the site or sites suitable for ponds, basins, and reservoirs

for water storage, and may reserve lands forming such sites from general sale and settlement and dispose thereof by sale or lease to be utilized for purposes within the purview of this act. He may also take such steps as he thinks necessary to protect the sources of water supply and to prevent any act likely to diminish or injure the said supply.

High-water marks, analysis of water, etc.

45. The minister may from time to time authorize the establishing in rivers, streams, lakes, and other waters, water gauges for computing the approximate volume and discharge of waters, the placing of high-water marks on rivers and streams, lakes and other waters when in flood, the taking of steps for securing analyses of the water of rivers, streams, lakes, and other waters, and the adopting of such other measures and proceedings for promoting the beneficial use of water, and for controlling and regulating the diversion and the application thereof as he finds necessary and expedient and as are consistent with the provisions of this act.

Expropriation of works by Government.

46. The governor in council may, if in the public interest it is at any time deemed advisable so to do, take over and operate or otherwise dispose of the works of any licensee authorized under this act: *Provided*, That compensation shall be paid for such works at their value—such value to be ascertained by reference to the exchequer court, or by arbitration, one arbitrator to be appointed by the governor in council, the second by the owner of the works to be taken over, and the third by the two so appointed, or in case these can not agree as to the third arbitrator, by the exchequer court—and that in estimating such value the court or the arbitrators may take into account the expenditure of the company and interest on such expenditure, and the value of its property, works, and business: *Provided also*, That no person who at such date is using the water of the said works shall be deprived of the quantity of water he is entitled to: *Provided further*, That in any such case the governor in council shall have due regard to the claims to consideration of any persons who have prepared or have in course of preparation any land to be supplied with water by the works taken over.

Proviso. **Proviso.** **Proviso.**

By-laws of company.

47. The by-laws and regulations of companies operating under this act shall not contain anything contrary to the true intent and meaning of this act, and shall be subject to revision and approval by the governor in council; and no tariff of charges for water furnished by any company shall come into operation until it has been approved by the governor in council.

General powers of minister.

51. The minister may—

Define the manner in which the measure of water shall be arrived at;

Define the duty of water according to locality and soil;

Define the portion of the year during which water shall be supplied for irrigation:

Fix the fee or charge to be paid for licenses issued under this act, which fees or charges may be varied according to the capital employed or volume of water diverted;

Regulate the extent of diversion from rivers, streams, lakes, or other waters;

Regulate the passage of logs, timber, and other products of the forests through or over any dams or other works erected in rivers, streams, lakes, and other waters under the authority of this act;

Regulate from time to time the water rates which may be charged by licensees, and the publication of tariffs of rates;

Prescribe forms to be used in proceedings under this act;

Impose penalties for violations of any regulation made under the authority of this act, which penalties shall in no case exceed a fine of two hundred dollars or three months' imprisonment, or both;

Regulate the manner in which water is to be supplied to persons entitled thereto, whether continuously or at stated intervals, or under both systems·

Authorize some person or officer, whose decision shall be final and without appeal, to decide in cases of dispute as to what constitutes surplus water as mentioned in this act:

Make such orders as are deemed necessary, from time to time, to carry out the provisions of this act according to their true intent, or to meet any cases which arise and for which no provision is made in this act; and further, make any regulations which are considered necessary to give the provisions of this act full effect.

Publication of regulations.

52. All regulations made and forms prescribed by the minister under this act shall be published in the Canada *Gazette* and shall be laid before both houses of Parliament within the first fifteen days of the session next after the date thereof.

Application of act to companies now existing. **53.** Any companies already formed to promote irrigation shall be subject to all the provisions of this act, except so far as the powers mentioned in section forty-eight are concerned.

Exemption. **54.** The provisions of sections forty-one, forty-eight, and forty-nine of this act shall not apply to any irrigation district incorporated under an ordinance of the Northwest Territories.

Repeal. **55.** The Northwest irrigation act, being chapter thirty of the statutes of eighteen hundred and ninety-four, and chapter thirty-three of the statutes of eighteen hundred and ninety-five, in amendment thereof, are hereby repealed.

WATER-RIGHT FORMS USED IN NORTHWEST TERRITORIES OF CANADA.

Regulations for the measurement and use of water, the disposal of reservoir sites and right of way for irrigation works, the establishment of gauge rods in streams and in rating flumes of irrigation canals and ditches, and the license and certificates to be issued, approved by his excellency the governor-general in council on the 29th day of April, 1895.

MEASUREMENT OF WATER.

SECTION 1. The measurement of the discharge of any stream, made for the purposes of determining the quantity of water available for licenses, authorizing the diversion of water therefrom, or to settle disputes between the holders of such licenses, shall be effected as follows:

The area of the actual water cross section, at time of measurement, shall be determined by careful measurement of the total width of stream, and by soundings under the line of cross section at sufficiently frequent intervals to give a close approximation of the contour of bottom of the stream.

The velocity of the stream shall be determined by measurement with any approved make of current meter, which must have been previously rated at the government rating station at Calgary, these measurements being taken at such intervals along the line of cross section as will enable the velocity to be determined for each subsection between soundings.

In streams of not more than three feet in depth surface and bottom velocities must be measured, or the meter may be moved slowly, during time of observation, from bottom to top and vice versa. In streams of more than three feet in depth, middepth readings of current meter may be taken, the resulting discharge being corrected by necessary factor for velocities thus determined.

(*a*) The flow of water into any irrigation ditch or canal shall be determined by careful measurement of the cross section of the rating flume, constructed as hereinafter provided, and of the velocity by current meter of the water flowing therein, at extreme low water, high water, and flood-discharge stages of water in the source of supply, these heights of water being fixed by the marking on the gauge rod placed in the said rating flume of such ditch or canal, as hereinafter provided. The flow of water between low, high, and flood stages of water shall be determined by a table showing flow of water at these heights, and for each six inches marked on the gauge rod, which table, in the form of a certificate, signed by the inspecting officer, shall be issued for each ditch or canal, and shall accompany the license hereinafter provided for.

(*b*) The quantity of water supplied to consumers by any person or company having a license for the use of water for irrigation shall be measured by water meter, measuring flume, measuring weir, spill box, or any other device for the measurement of the water, but such water meter, measuring flume, measuring weir, spill box, or other device must be first approved and sanctioned by the minister of the interior, or by some officer appointed by him, who shall issue a certificate authorizing the person or company to use such device.

(*c*) The volume of water in any lake, pond, or reservoir, or other body of still water, shall be measured by careful survey of the outline of such body of water to determine its superficial area, and measurement of the depth of water at sufficiently frequent intervals to give a correct contour of the bottom of such lake, pond, or reservoir, so that the contents thereof may be accurately calculated. The flow of water into or out of any reservoir shall be measured by determination of the area of the cross section of channel of inflow or discharge and of the velocity of the water flowing therein by current meter.

(*d*) The discharge of spring shall be determined by causing all the water flowing therefrom to discharge into a vessel or reservoir of known contents, and noting

the time taken to fill such vessel or reservoir, or by measurement of cross section of the channel carrying flow of such spring, as near as possible to its head, and determination of velocity of flow therein with current meter.

DUTY OF WATER.

SEC. 2. The duty of water, or the ratio between a given quantity of water and the amount of land it will irrigate, shall be one hundred acres for each cubic foot of water per second flowing constantly during the irrigation season, and all applications for water to irrigate any given area, and the division of the available water supply among applicants therefor, shall be made upon the basis of this duty of water.

LICENSES.

SEC. 3. Whenever any company or person, applying for a license or authorization under the provisions of the act, has complied with all the requirements thereof, and has completed the construction of the works authorized, an inspection of the works shall be made by an officer named by the minister, who shall determine the capacity of such works and certify that they have been completed in accordance with the provisions of the act.

(*a*) Upon receipt of such certificate, and of a fee of ten dollars, to be paid by the company or person constructing such works, the minister of the interior shall issue to such company or person a license in the form given in the schedule hereto, which license shall be registered by the company or person to whom it is issued in the registry office in and for the district within which the lands affected by the system covered by such license are situated, by producing the same, or an exemplification thereof, to the registrar, with a true copy, sworn to by any person who has compared the same with the original, and the copy shall be filed with the registrar.

RATING FLUME AND GAUGE RODS.

SEC. 4. Every irrigation ditch or canal shall be provided by the owners thereof with a rating flume, which is to be constructed in the ditch or canal not less than one hundred nor more than eight hundred feet between the head gate thereof, such flume to be built in accordance with plans approved by some officer appointed by the minister.

(*a*) Every rating flume shall be provided with a gauge rod, which is to be placed on the side at the center of such flume. The gauge rod shall be two inches in thickness and three inches wide, painted white, with heights above the floor of the rating flume clearly marked thereon in feet and tenths of a foot with black lines and figures. The height of low water, high water, and flood stage of water shall be shown on the gauge rod at elevations to correspond with the marking of these stages of water on the government gauge rod placed in the stream from which water is taken for such ditch or canal.

GOVERNMENT GAUGE RODS.

SEC. 5. The minister may authorize some officer to place a gauge rod, or rods, in all streams or reservoirs used as a source of supply for irrigation ditches or canals. The gauge rod, or rods, are to be permanently placed at some point for convenient reference, and clearly marked, so that the rise or fall of water in such stream or reservoir can be readily noted therefrom. The height of low water, high water, and flood water shall be designated on the rod with special marks and lettering, so that these stages of water may be apparent by inspection.

RESERVOIR SITES.

SEC. 6. The lands forming sites suitable for ponds, basins, and reservoirs, which have been reserved from general sale and settlement, may be leased to any company or person applying therefor who have satisfied the minister of their or his ability to construct the works necessary to utilize the proposed site for the storage of water and the beneficial use of the same in irrigation.

(*a*) The lease shall be for one year, with privilege of renewal from year to year, provided the lessee continues to use the lands for the purposes mentioned, and complies with all the provisions of the irrigation act.

(*b*) The rental to be paid for lands leased for reservoir purposes shall be one cent per acre per annum, payable upon the first day of November in each and every year.

(c) Should the lessee at any time cease to use the lands for the purposes mentioned, the lease shall be cancelled and the lands become available for lease to any applicant therefor who shall have satisfied the minister of his ability to utilize the lands for the beneficial storage of water.

RIGHT OF WAY.

SEC. 7. The right of way for any irrigation ditch or canal, or for the works connected therewith, through any and all lands, the title to which is vested in the Crown, as shown by the plans and books of reference filed in the department of the interior and approved by the surveyor-general, may be granted to the company or person constructing such irrigation ditch, canal, or works in connection therewith free of charge.

Schedule. Form of license. Department of the Interior.

[Coat of arms.]
—— License No. ——. Source of supply ——. First issued ——.

Know all men by these presents, that by virtue of the authority vested in me by the Northwest irrigation act, I, —— ——, minister of the interior of Canada, do hereby grant unto —— ——, hereinafter called the licensee, —— executors and administrators, full right, power, and license, subject to the conditions and restrictions contained in the Northwest irrigation act, to divert from the —— the following quantity of water, for use in the —— system constructed by ——, and as shown by application of the licensee and by the plans of the same, dated the —— and filed in the department of the interior and in the registry office in and for ——, and authorized by order in council dated ——, 189—, that is to say: At flood level, —— cubic feet per second; at high water, —— cubic feet per second; at low water, —— cubic feet per second; and to take and keep possession of the said quantity of water for and during the period during which this license may be in force under the provisions of the Northwest irrigation act.

But this license shall be subject to the following conditions, viz:

1. That the license shall only come into force and effect after it has been registered by the licensee in the registry office in and for the ——.
2. That the period of flood discharge, high water and low water in the said —— shall be fixed and determined by the marking on the gauge rod placed in the said stream by the department of the interior.
3. That this license shall be subject to forfeiture, as provided by the Northwest irrigation act.
4. That this license can only be assigned or transferred by approval of the minister of the interior and by using the form printed on the back thereof, and that such transfer must be recorded in the department of the interior and in the registry office in and for —— before a new license will be issued in name of transferee.

Dated at Ottawa, this —— day of —— one thousand eight hundred and ninety —.

Witness:

—— ——.

—— ——.

Deputy Minister of the Interior.

——. License No. ——. Source of supply. ——. The minister of the interior to —— ——. License to divert water for —— —— from ——. Recorded in ——.

Transfer.

—— —— for and in consideration of the sum of —— dollars to —— in hand paid (the receipt whereof is hereby acknowledged), do hereby sell, transfer, and make over to —— ——, executors and administrators, all my right, title, and interest of in and to the license within contained.

In witness whereof I have hereunto set my hand at —— this —— day of ——, 189—.

—— ——.

Witness:

—— ——.

Memorial filed in accordance with provisions of section — of the Northwest irrigation act.

The memorial of ——— ———, of section ——, township ——, range ——, west of the —— meridian, in the district of ———, sheweth:

1. That the name— and residence— of the memorialist— are set forth above, and that —— occupation ——— and —— post-office address is ———.

2. That the memorialist— ask— for authority under the provisions of the Northwest irrigation act to divert from ———, on the ——, quarter of section ——, in township ——, range ——, west of the —— meridian, —— cubic feet of water per second to be used for —— purposes on the following lands, viz. ———, and comprising a total acreage of —— acres, and to construct the necessary works to enable the water so diverted to be used for the said —— purposes.

3. That the works proposed to be constructed consist of ———, and the location of and proposed method of constructing these works are shown on the maps, plans, profiles, and specifications accompanying this memorial.

4. That the financial standing of the memorialist— is as follows: ———, and that the probable expenditure necessary to complete the proposed works will not exceed $——.

5. That the extent of settlement along or in the vicinity of the said ——— is ——— residents.

6. That the probable number of the consumers of the water to be diverted is ——.

7. That the character of the land upon which the water is to be used is ———, and the value of such land in its present condition, with improvements, is $—— per acre.

To ——— ———.

Dated at ———, ———, 189–.

Certified a true copy of the memorial filed with the ———, this ——— day of ———, 189—.

——— ———,
Chief Inspector.

O

U. S. DEPARTMENT OF AGRICULTURE,

OFFICE OF EXPERIMENT STATIONS.

A. C. TRUE, Director.

WATER-RIGHT PROBLEMS

OF

BEAR RIVER.

BY

CLARENCE T. JOHNSTON and JOSEPH A. BRECKONS.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1899.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., June 28, 1899.

SIR: I have the honor to transmit herewith two papers on water-right problems of the Bear River, which runs through Wyoming, Utah, and Idaho, prepared in accordance with instructions from this Office under the direction of Prof. Elwood Mead, expert in charge of irrigation investigations. The first paper, by Clarence T. Johnston, assistant in irrigation investigations, deals with the water supply of Bear River and its diversion, and the second, by Joseph A. Breckons, discusses interstate water rights in Bear River.

These papers were prepared in pursuance of the purpose of the Office to inaugurate its study of the irrigation question by the collation and publication of information regarding the actual status of irrigation in the arid regions as regards laws, institutions, etc. Two bulletins bearing upon this phase of the subject have already been published, one (No. 58) discussing water rights on the Missouri River and its tributaries, the other (No. 60) giving an abstract of the State laws governing the appropriation of water from the same streams, with the legal forms in use in the several States forming the basin of the Missouri River.

Since few of the more important streams used for irrigation lie wholly within the limits of any one State, and there is great diversity of irrigation laws in different States, interstate complications over water rights have been frequent, and must become more frequent and more acute as the demand for water increases, unless some mode of settlement is devised.

The present bulletin is largely a statement of these interstate questions as illustrated in the Bear River Valley. This river was chosen for study because in its course of a little over 300 miles it crosses State lines (Wyoming, Idaho, and Utah) five times, finally emptying into Salt Lake, which is less than 50 miles distant from its source, thus presenting in small compass a great variety of interstate problems, and offering exceptional opportunities for the inauguration of this class of inquiries.

The bulletin is respectfully submitted, with the recommendation that it be published as Bulletin No. 70 of this Office.

Respectfully,

A. C. TRUE,
Director.

Hon. JAMES WILSON,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
IRRIGATION INVESTIGATIONS,
Cheyenne, Wyo., June 15, 1899.

SIR: I have the honor to submit herewith a discussion of the "Water-right problems of Bear River," by Clarence T. Johnston and Joseph A. Breckons.

The underlying purpose of this bulletin is to present some of the water-right complications of interstate streams. Bear River exhibits an unusual number of these in concrete form. A simple statement of its conditions brings out more clearly than any abstract discussion the problems which a disregard of drainage lines in the establishment of State boundaries has created.

For the past ten years people in Wyoming who use water from this river for purposes of irrigation have been clamoring for an establishment and protection of their rights according to the State laws. They have complied with its terms, paid the recording fees, made and filed maps to show the location of ditches and land reclaimed; but all to no purpose. The man who has paid no attention to the State irrigation code fares as well as the one who has fulfilled all its requirements. The State irrigation authorities have determined the priorities and amounts of appropriations on contiguous State streams, and water commissioners protect these in times of scarcity. They can do nothing for the irrigators along Bear River. So far as practical results are concerned the State laws do not apply. It is useless to determine priorities of ditches wholly within the State, when later ones with head gates across the border in Utah can not be closed because the water commissioner's authority does not extend that far. To close down the ditches around Evanston, Wyo., would not add to the water supply of the earlier Wyoming appropriators 35 miles north of there; it would simply raise the water level of the Utah ditches which irrigate Woodruff Flats. A determination of priorities along two sections of a stream, with an intervening section left undisturbed, would accomplish no useful purpose; hence the Wyoming irrigation authorities have delayed an adjudication until some provision is made for including head gates on the Utah as well as on the Wyoming side of the boundary. Nor is the plight of Utah irrigators in the Woodruff Valley any more satisfactory. As the

Yellow Creek and Hilliard ditches in Wyoming are extended they see later rights taking more and more of their water supply, and while both States recognize the superior claim of a prior user, lack of concerted action causes his claim to be ignored.

It is unfortunate that the future importance of irrigation was not recognized when State boundaries were being established. A change of 500 square miles either way would have disposed of the interstate problems of Bear River. It would have thrown all the controverted portion of the stream into either Utah or Wyoming. There are scores of similar instances along the boundaries of these and other arid States. The re-forming of these boundaries is now practically out of the question, but the enactment by the different States of uniform irrigation laws, and the entering into amicable agreements for the protection of irrigators' rights, are not only possible, but ought to be among the early results of the evolution now taking place.

The most effective means of promoting this is to study and give publicity to the facts. The discussion by Mr. Breckons of the change in property rights in this river the moment its waters cross an invisible barrier can scarcely fail to lead in the near future to a less violent difference in the laws which govern these rights.

The description of physical conditions by Mr. Johnston will have a local value in relieving anxiety on the lower part of the river by showing that there is no danger of diversions above creating a disastrous scarcity below; in removing the interstate jealousy by showing that the contribution of each State to the river's supply has an approximate relation to the ultimate use in that State; and by showing that relief from existing evils can be had by improving the remarkable opportunities for storage rather than through litigation over the natural flow.

Respectfully,

ELWOOD MEAD,
Irrigation Expert in Charge.

Dr. A. C. TRUE, *Director.*

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ILLUSTRATIONS.

WATER-RIGHT PROBLEMS OF BEAR RIVER.

THE WATER SUPPLY OF BEAR RIVER AND ITS DIVERSION.

By CLARENCE T. JOHNSTON.

WATER SUPPLY.

The use of the water in Bear River for irrigation has given rise to some water-right questions which have made it one of the noted streams of the arid region. Another claim to distinction is the fact that it is the largest stream emptying into Great Salt Lake, and the largest river in the Western Hemisphere whose waters do not reach the ocean.

From its source in the mountain lakes of Summit County, Utah, to where it empties into Great Salt Lake in the same State, the river is over 300 miles long. In that distance its fall is over 1 mile, and the 300 miles of its course finally end in its discharge into a lake less than 50 miles from its source. Its head waters could reach Salt Lake much more readily by way of the Weber, and their diversion into this stream has been several times under consideration. If this should occur, another complication would be added to those already existing. Another peculiar fact is that its source in the Uinta Mountains, its mouth at Great Salt Lake, and its most northerly bend in Idaho form the three points of an isosceles triangle, the base of which is 140 miles long and the other sides each 90 miles. The map of the river (Frontispiece) shows its remarkable affinity for State boundaries. Within the first 100 miles of its course it manages to cross the western and southern boundaries of Wyoming four times. In its entire course these boundary crossings divide the stream into six sections. Ditches heading in each of these sections are practically independent of irrigation laws or the superior claims of appropriators of water below.

Beginning at the head, it crosses the Wyoming-Utah line 9 miles east of the southwest corner of Wyoming. Just below the State line a proposed ditch is to return the water to Utah through the channel of Yellow Creek. Ditches taken out south of the Wyoming border pay no attention to prior rights north of it; their head gates stay open, even if the head gates of earlier ditches front on a dry channel. For the next 38 miles Wyoming irrigators have control of the river, after which it

deserts them by returning to Utah. The bend on the western side of the boundary is 22 miles long, in which distance Utah head gates are numerous. The stream then turns to the east and again enters Wyoming to receive a number of tributaries from the Salt River range, which more than replace all the water diverted above. The length of this last Wyoming section is about 25 miles, and it extends north of the northern boundary of Utah, so that, when the river turns west again, it enters Idaho.

The Idaho loop has two interesting features—the automatic regulation of floods by Bear Lake and the abrupt bend of the river when almost across the divide into the drainage basin of Snake River, where it cuts through a lofty range to enter Cache Valley, Utah. At the southern edge of Cache Valley it becomes again a picturesque river, roaring and tumbling through a mountain canyon, where it cuts through the range which separates Cache and Salt Lake valleys. In the 2 miles of its passage through this canyon the total fall is about 160 feet.

CHARACTER OF THE WATER SUPPLY.

If all of the water supply came from the mountains at the head there would be in effect six independent sets of claims to supply, and controversies over the diversion of the water would long ago have become acute. But this is not the case; the stream grows from the lake where it starts to the larger one where it ends. While irrigators in each of the six sections take something from the river, there are tributaries which reenforce it. As a result, the maximum measured discharge at Evanston, Wyo., of 950 cubic feet per second, becomes over 10,000 cubic feet per second at Collinston, Utah. Smiths Fork, which rises in Wyoming and empties into the stream in the last section in that State, carries a much larger volume than the main stream above their junction. Logan River adds more to its volume than all the appropriators in Wyoming can divert. Henrys Fork is an important feeder, and Bear Lake and the streams which drain into it afford a material increase to its low-water discharge. The exceptional increase due to these tributaries and the facilities for storage practically restrict interstate complications over rights to the four upper sections along the boundary between Utah and Wyoming. This progressive increase in volume is one of the complications which will vex those who attempt to frame a code of laws for the interstate division of streams. On Bear River there is not one, but a dozen important sources of supply, the volume and availability of which will have to be considered. Wyoming and Utah are the important contributors to and depleters of the stream. But little water is either added to or taken from it in Idaho.

IMPORTANCE OF SUBTERRANEAN WATER SUPPLIES.

The value and availability of a river can not be measured by a gauging at any point in its flow nor by a measurement of its surface supply.

Its gains and losses from subterranean sources are much more important than have heretofore been supposed. Thus 40 miles east of Bear River is a stream which in 10 miles loses in the rocks of its channel more water than Bear River carries during nine months of the year. In Bear River, on the contrary, there is a marked gain from seepage and the probable presence of unlocated springs which rise in the river's bed.

MEASUREMENTS OF THE DISCHARGE OF BEAR RIVER.

In September, 1898, the writer made a personal examination of that portion of the stream where the supply is at times insufficient to meet present needs. This included the four sections formed by the Wyoming-Utah boundary. Measurements were made to determine the loss from ditches, the increase from seepage, and the size of the several tributaries which enter the stream in this portion of its length. It was near the close of the irrigation season and at the time of least discharge—favorable conditions for examining the ditches and for locating the places of gain and loss from seepage and for measuring the amount of gain or loss.

The measurements began with a gauging of the stream's discharge above all the ditches, the place chosen being near the southern boundary of Wyoming. There was 57 cubic feet per second flowing in the stream at this point. A second gauging was made farther down, 6 miles above the point where the stream leaves the State to enter Utah. The discharge here was 43.5 cubic feet per second. Between this point and the State line two large ditches connect with the river in order to irrigate lands in Utah, the two ditches practically exhausting the stream. A gauging below the head gate showed only 3.5 cubic feet per second remaining. An examination of the map will show that for a considerable distance below this point there is no material addition to the stream from surface tributaries. If there had been no return seepage the volume left in the river would have been lost by evaporation before the bend in Utah had been traversed, but the increase in seepage below this point was quite marked. At the head of the Booth and Crocker and Randolph and Woodruff canals, which tapped the stream 6 miles west of the line, the discharge of the river was between 15 and 20 cubic feet per second. The first of these canals diverted about 8 cubic feet and the last about 9, leaving about 5 cubic feet per second remaining in the stream. For the next 22 miles there was no perceptible gain from seepage or other source, the river remaining practically unchanged until the mouth of Smiths Fork was reached. A gauging made immediately below the confluence of these two streams showed a discharge of 213.67 cubic feet per second. The discharge of Smiths Fork was 210 cubic feet per second, or nearly four times the flow of Bear River above all ditches. Smiths Fork drains a larger and higher mountain area than does the main stream at its head, and those familiar with both streams

FIG. 1. THE "TURNPIKE," NORTH SHORE OF BEAR LAKE, IDAHO.

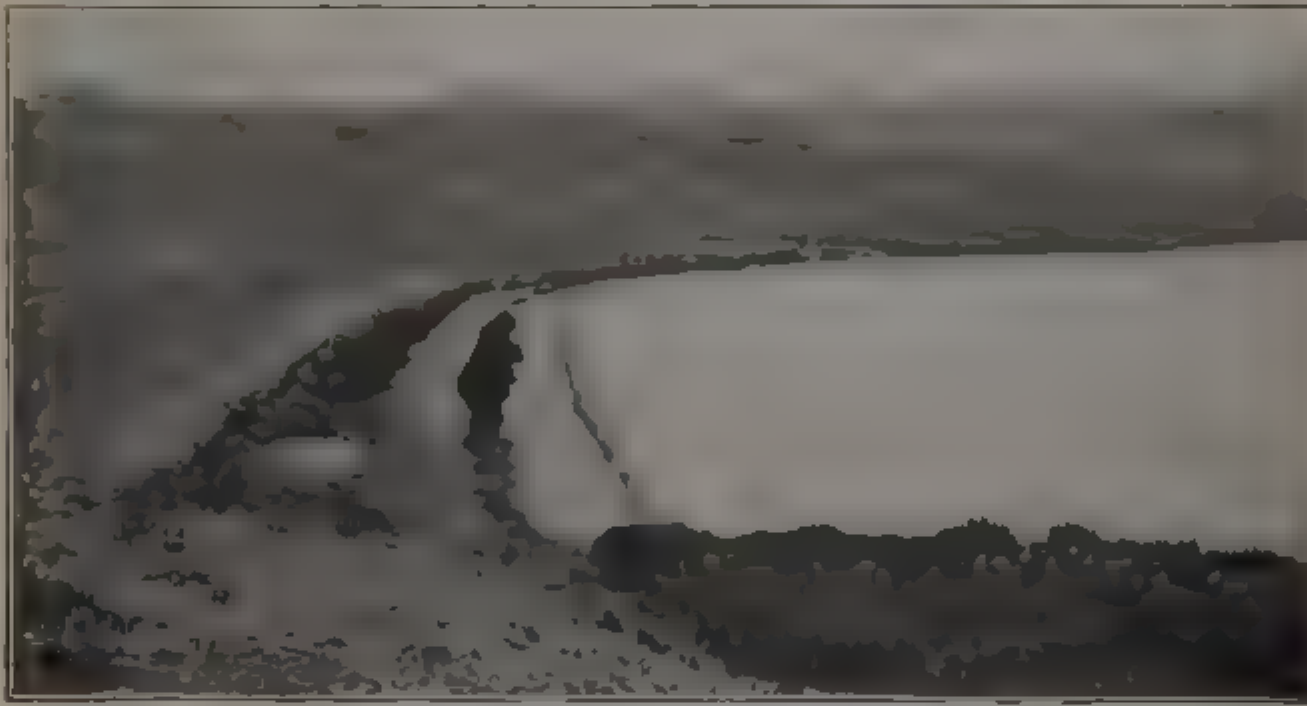


FIG. 2. SOUTHERN SHORE OF BEAR LAKE, UTAH.

FIG. 3. WESTERN SHORE OF BEAR LAKE, ON UTAH-IDAHO LINE.

At the north end of the lake are the lagoons and marshes which border its outlet, and which extend toward Bear River a distance of 6 or 7 miles. Between these marshes and the lake proper is a narrow and almost level ridge of sand, known locally as "The Turnpike" (see Pl. II, fig. 1), which extends from the hills on one side of the valley which the lake fills to the hills on the other. About half way across this separating ridge, which is in effect a natural dam, is the outlet of the lake, a channel which connects Bear Lake and the marshes. This channel is only 38 feet wide, and all that is required to convert Bear Lake into a reservoir is the building of a set of head gates to regulate the discharge of water, and the raising of the low places in "The Turnpike" throughout the 2 or 3 miles of its length. If this were done a rise of 5 feet in its water level would add over 400,000 acre feet[1] to the low water supply of irrigators below. It is doubtful if the streams which empty directly into Bear Lake would furnish this, but an additional supply could be secured by the construction of a ditch from Bear River emptying into the lake. This would not have to be more than 15 miles long, and it could be made large enough to divert practically the entire discharge of the river for March, April, and May of each year.

The waters of the lake reach Bear River about 18 miles from the outlet. The river runs within 12 miles of the lake, but at the nearest point it has thrown up a low ridge along its southern bank (Pl. II, fig. 2), which prevents the river flowing into the lake basin. Judging from the water marks along the hills bordering the valley, the lake at one time covered the entire area and was between 40 and 50 miles long and from 50 to 100 feet deeper than it is at the present time. Its subsidence has left large fertile areas along the north and west shores (Pl. II, fig. 3) of the present lake. On the south there is also considerable farming land, irrigated from small creeks. Numerous small streams enter the lake from the west and serve to irrigate a considerable portion of the tillable lands on that side. This side of the lake is now an almost continuous orchard, where twenty years ago an attempt to raise even the hardiest cereals was considered a hazardous undertaking.

Nothing has as yet been done toward the improvement of this lake, the reason being that it is below the section of the stream where a scarcity has as yet been experienced. To forestall litigation reservoirs will have to be built at the headwaters of the stream. There are a number of lakes south of the Wyoming line, but no examination was made to determine either their capacity or the cost of their improvement.

FORMER CONDITION OF UPPER BEAR RIVER.

The old water levels marked on the hills bordering the valley of Bear River make it manifest that Bear Lake is the last remnant of a chain of lakes which formerly extended along the river to the southern

[1] An "acre-foot" of water is the volume required to cover an acre of land to a depth of 1 foot, or 43,560 cubic feet.

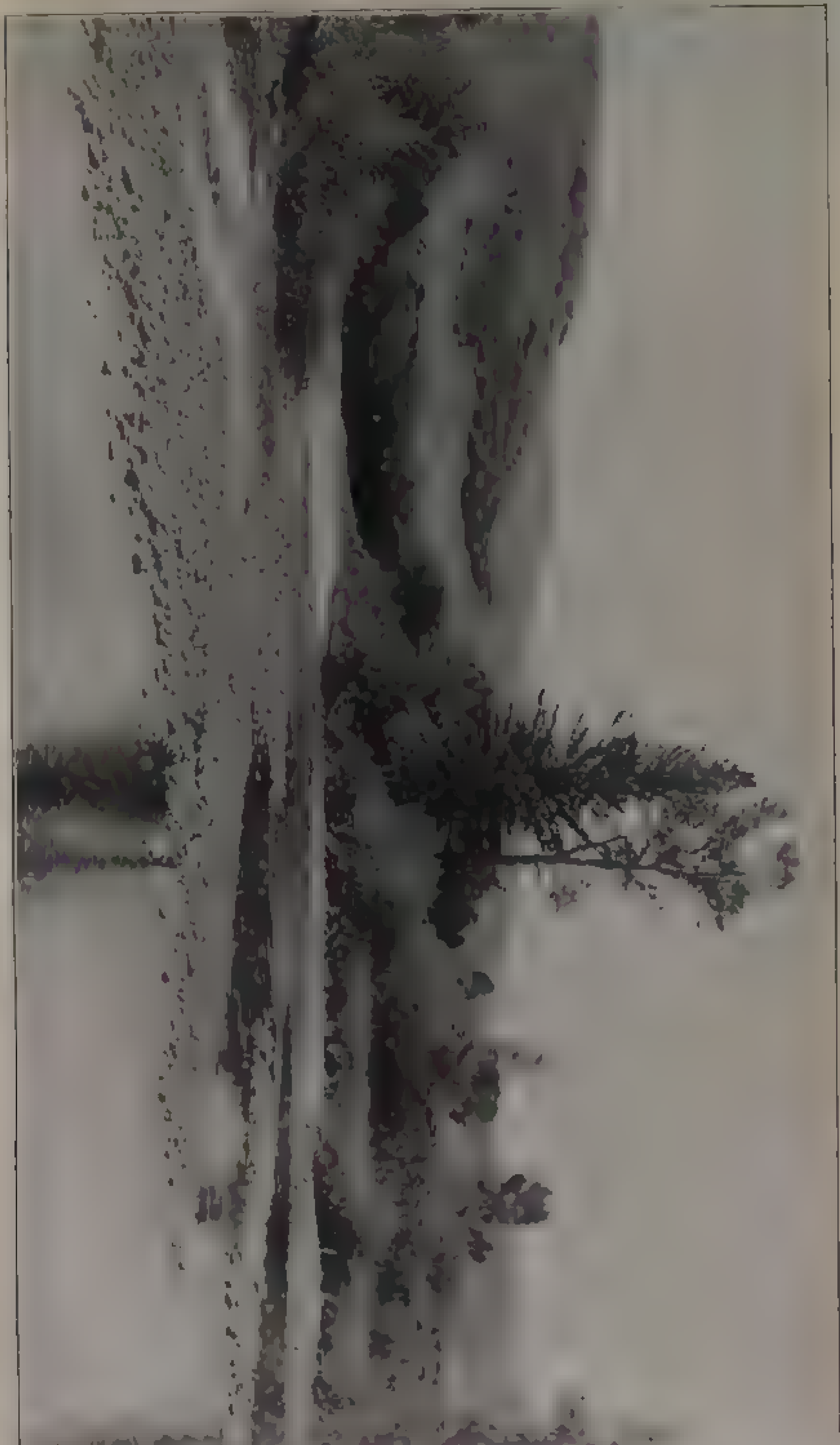
boundary of Wyoming (Pl. III). Two causes have operated to destroy these lakes—the river has lowered their line by cutting down their outlet, while the sediment carried down from above has filled the basins. Bear Lake has been saved from being filled with sediment by the low ridge which lies between it and the river. The former location of these lakes can be easily traced out by the broad and level alluvial deposits through which the stream winds its sluggish course. The first lake was located about 12 miles south of Evanston, Wyo., near the southern boundary of the State. It had a length of nearly 10 miles and an average width of 2 miles. Below it is a canyon, known locally as "The Narrows," where the river has a very rapid fall, and the indications are that at one time there was either a rapid or a cascade in the channel at this point. The second lake began near the mouth of Sulphur Creek and reached to the second canyon. This had a length of 22 miles and an average width of nearly a mile. The canyon at this point is not worn so deep, proportionately, as the one above, and for the entire distance there is not, except during high water, a ripple in the current of the river. The third and largest lake basin begins below "Narrows No. 2," and spreads out on either side of the present river channel from 2 to 14 miles. It has a length of over 50 miles. That these level bottoms were formerly basins which have been filled to a great depth with sediment is clearly evident. In the midst of these level plains are isolated points, the summits of what were once high foothills. They stand out like islands in the ocean, all but the summits having been submerged in the river's deposit and glacial drift from above.

LOCATION AND CHARACTER OF THE IRRIGATION WORKS ALONG BEAR RIVER.

The 100 miles of Bear River above the mouth of Smiths Fork is the portion which has been productive of water-right complications. Here in August the demand for water often exceeds the supply. The ancient lake beds above described are fertile and easily reclaimed, and the number of ditches built to water them is indicated by the fact that there are 150 recorded in the Wyoming State engineer's office alone. Adding to these the number built to water Woodruff Flats, in Utah, there must have been in September, 1898, over 200 claims to the 47 cubic feet of water per second which crossed the southern boundary of Wyoming. Nearly all these are small individual ditches less than a mile in length. They are not shown on the map, because the scale used was not large enough to permit of locating the head gates, much less to draw the lines of the ditches.

The country irrigated is in the midst of an extensive grazing area used by the owners of range flocks of sheep and herds of cattle, and the growing of winter feed for live stock is the leading industry.

The river rises among the loftiest peaks of the Uinta Range, amid picturesque scenery in which deep snow-filled canyons and a number



BEAR RIVER, NEAR SOUTHERN BOUNDARY OF WYOMING.

of glacial lakes are the chief attractions. When it leaves these it emerges into a broken foothill country which is partially covered with pine timber. Much of this region has been devastated by fire. In many places aspen groves have sprung up where blackened tree trunks would otherwise mark the vanished forests of pine. The removal of the timber in this broken country has destroyed the natural reservoir system of Bear River. Formerly the snow lingered late, and springs were abundant on the hillsides, but conditions have so changed that artificial reservoirs are now being discussed. The foothills extend almost to the Wyoming line, where they break away as the river turns to the northwest. The channel of the stream follows close to the hills on the west side for 7 or 8 miles below the line. On the east side a low, flat divide runs to Mill Creek, the first tributary of Bear River on the east. This divide is a mass of water-worn pebbles and bowlders, and the entire area is covered with a dense growth of sagebrush. Ditches tap Bear River near the boundary and cross the Mill Creek divide at almost right angles to the main stream. There is more cultivated land along Mill Creek than along Bear River above their junction.

"HILLIARD FLATS."

Two ditches cross both the Mill Creek watershed and a second divide to irrigate land along Sulphur Creek. This land is known locally as "Hilliard Flats." It is separated from the valley of Bear River by a high range of hills. These break off on the south, thus allowing water to be carried into the valley at small expense. The area capable of being irrigated approximates 8,000 acres, and water can be easily distributed over the entire area. The southern half of the valley is settled, although not over one-tenth of the irrigable land is cultivated. The soil varies; along the hills on both the eastern and western borders it is the black loam often seen in mountain valleys; through the center of the valley, running north and south, is a gravelly ridge well adapted to cereals and forage crops. Sulphur Creek follows along the east side of the valley. It is of little importance as a source of water supply, as it furnishes but a small quantity at any time in the year. The older residents of the valley all state that before the timber on the head waters of the creek was destroyed it maintained a large and perennial flow.

YELLOW CREEK.

There is a somewhat similar valley on the west side of Bear River along Yellow Creek. A canal has been surveyed to carry water over the divide between the river and this tributary. The line follows the river for some distance along an almost vertical bank. It is but little longer than the Hilliard Flats ditch, but more expensive. The area capable of being irrigated approximates 12,000 acres, and is distributed along the creek for 15 miles. The estimated cost of this ditch is $4,000.

[illegible] the ground is [illegible] the limits of agriculture. The [illegible] to utilize land [illegible] below the mouth of Mill [illegible] the valley is a mile and a half [illegible] alfalfa meadows, cultivated [illegible] below the mouth [illegible] there are no meadows [illegible] Creek, where it again [illegible] reported to us [illegible] the mouth of Yellow Creek the valley of [illegible]

[illegible]

[illegible] above the mouth of [illegible] in every direc- [illegible] as high [illegible] some water [illegible] The owners of [illegible] water they tend to alter the [illegible] Ditches below [illegible] Evanston on [illegible] wherever con- [illegible] long, while [illegible] this water- [illegible] water from it are [illegible] continuously until [illegible] the town of [illegible]

[illegible] the river turns to [illegible] miles from [illegible]. The entire [illegible] narrows is con- [illegible]. The valley is a con- [illegible] better repair [illegible] stream.

The multiplicity of headgates and ditches is a characteristic feature of Bear River irrigation works, Wyoming. Another is the parallel construction of ditches to water land below all of them. On the west bank of the river, opposite the mouth of Sulphur Creek, are the heads of four ditches. There are places along them where all are in view on the same hillside. Each ditch above is a menace to all below. The extent of damage occasioned by a break in one depends on how many are below and how much water each ditch is carrying. This multiplicity of parallel ditches indicates a lack of cooperation among farmers not met with in either Idaho or Utah.

FIG. 1. CATTLE RANCH NEAR EVANSTON, WYOMING.

FIG. 2. RANCH 15 MILES SOUTH OF EVANSTON, WYOMING.

FIG. 3. FARM 10 MILES EAST OF WOODRUFF, UTAH.

Three miles below Evanston the Chapman Canal begins. It is the most important canal along the river in Wyoming, although of the 47,680 acres of land it irrigates but 10,088 lie in that State. The canal was measured a short distance below its head gate. It is 18 feet wide on the bottom, 24 feet wide on the top, and 4 feet in depth, with a grade of 3 feet per mile. These dimensions give a carrying capacity of approximately 252 cubic feet per second. The ditch is well constructed, although it follows the contour of the ground too closely for a channel of its dimensions. Each irregularity in the surface of the ground has a corresponding curve in the ditch. This not only detracts from its appearance, but adds much to the erosion of the banks.

"WOODRUFF FLATS."

Immediately below the second narrows the river crosses into Utah and at once widens. This valley is locally known as the "Woodruff Flats." The Woodruff Flats extend to the south for 12 miles, and as the river turns to the north the valley has a width varying from 4 to 7 miles until the river returns to Wyoming, where the valley becomes much narrower, being but little over a mile in width. The land reclaimed in Utah is irrigated by larger canals, and the methods of the farmers are much superior to those followed in Wyoming, either above or below this tract. (Pl. IV, fig. 3.)

Four miles below the narrows the Randolph and Woodruff Canal connects on the west side of the river. This canal is 24 feet wide on top, 20 feet wide on the bottom, and 4 feet in depth. For the first 3 miles it has a fall of 30 inches per mile. The grade decreases below this to 20 inches per mile, which fall is maintained to the end. It has a carrying capacity for the first 3 miles of 220 cubic feet per second and for the remainder of the distance of 114 cubic feet per second. The local theory for having the greatest fall at the head of the ditch and decreasing it as the cross section diminishes is that when water is once started in a ditch the quantity can be held. The ditch is thus regarded as a species of funnel. That this practice is wrong is evident from the appearance of the channel at the upper end of the canal. A fall of 30 inches per mile is too great, and the channel has washed wherever the material is anything but solid rock or gravel. The material washed out must be deposited along the lower part of the canal, where the current is not swift enough to carry the sediment. The canal covers a valuable tract of land averaging 4 miles in width, a large portion of which is now under cultivation. Oats, wheat, rye, and garden products are the principal crops, but the cultivation is superior to that seen on the stock ranches found above in Wyoming. Considerable land is irrigated below Randolph from the same canal.

On the east side of the river is the Booth and Crocker Canal, 20 feet wide on top and 2 feet deep, which irrigates a narrow strip of land lying between Bear River and the Bear River Mountains. This canal

is 20 miles long. Near its terminus the Otter Creek Canal connects with the river on its west bank. It irrigates a large area of natural meadow land. It is 30 feet wide and 3½ feet deep. (Pl. V, fig. 1.)

BECKWITH RANCH.

The Beckwith Company has three ditches. The first of these co nects with the river on the west side, 6 miles above the Wyomi line. It is 30 feet wide on top, 25 feet wide on the bottom, and 4 f deep. The other two canals of this company leave the river 2 mi below the Wyoming line. The most expensive dam on this section the stream serves to raise the water to fill these canals. (Pl. V, fig. The ditches have no head gates. The dam has regulating gates wh can be closed and the level of the river raised to flow into the cana The dam is a rock-filled crib structure, having a roadway built over t cribs and large quantities of loose rock thrown in above them. T gates are placed on the upper side of the dam and are so arranged to be worked by one man.

WYOMING AND IDAHO DITCHES.

The valley of the river from this point to the junction of Bear Ri and Smiths Fork has an average width of 1½ miles. Immediately bel the confluence of the two streams are the third narrows. The Wym and Irwin canals begin below them. Like the Beckwith canals, o dam suffices for the two and no head gates have been construct (Pl. V, fig. 3.) Numerous small ditches have been built between th canals and Bear Lake Valley. Henrys Fork flows into the main stre from the north beyond the Wyoming line. Here the valley of the riv is from 2 to 4 miles wide, but it becomes narrower just below and co tains little irrigable land until Bear Lake Valley is reached. In th valley the four ditches taken from the stream serve to irrigate 16,0 acres. From Bear Lake Valley, Idaho, to the Cache Valley, in Uta the hills approach close to the river, and only a limited area can b reclaimed.

CACHE AND GENTILE VALLEYS.

Some 15 miles below Soda Springs several small tributaries furnis water for the irrigation of a tract of land known as Gentile Valley. Th land is rolling, and many of the hillsides are under cultivation. Bu one ditch is taken from the main stream, and it only serves to irrigat a small area of bottom land. The river is in a deep channel and th grade is light, thus making it almost impossible to take water from it by canals without the construction of a high and expensive dam at the head.

Cache Valley is chiefly irrigated from the tributaries of Bear River. Of these Logan River is the most important, although Cub Creek, Blacksmith Fork, and Box Elder Creek furnish water for large tracts.

FIG. 1. DAM FOR THE OTTER CREEK CANAL, UTAH.

FIG. 2. DAM FOR THE BECKWITH CANAL, WYOMING.

FIG. 3. DAM FOR THE WYMAN AND IRWIN CANALS, WYOMING.

FIG. 4. DAM FOR BEAR RIVER CANAL, UTAH.

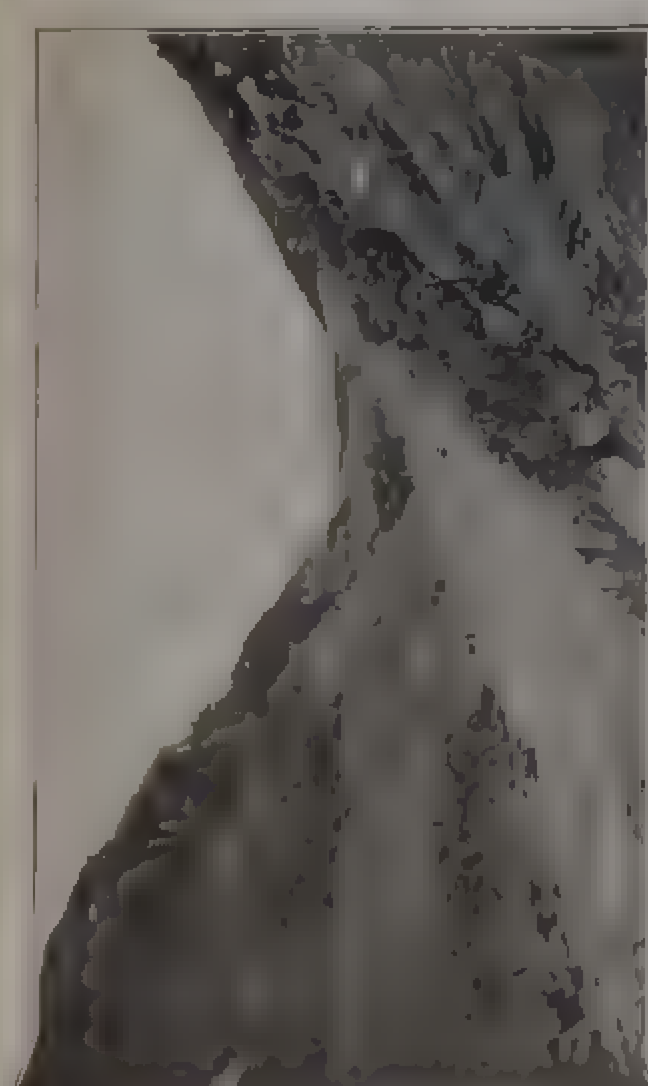


FIG 1 BEAR RIVER CANYON UTAH

FIG 2. PLANK FLUME ON BEAR RIVER CANAL.

FIG 3 TUNNELS AND RETAINING WALLS ON BEAR RIVER CANAL.

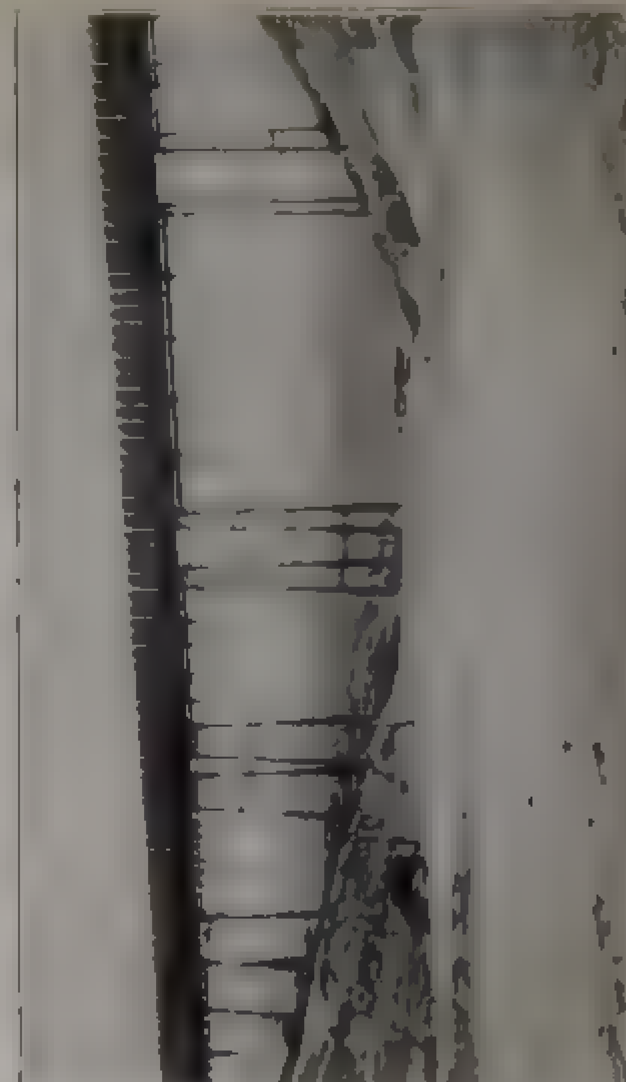


FIG 4. FLUME ACROSS MALAD RIVER, BEAR RIVER CANAL.

This valley is known as the granary of Utah, and well deserves the name, as more grain is grown here than on any other one tract in the State. The water of the streams is used to the best advantage, and a large amount of money and labor has been expended in the construction of reservoirs. Newton Reservoir is the most important of these. It has a capacity of nearly 900 acre-feet.

BEAR RIVER CANAL.

Immediately below the junction of Logan River and Bear River, Bear River Canyon (Pl. VI, fig. 1) begins. At the upper end of this canyon are the diverting dam and head gates of the Bear River Canal (Pl. V, fig. 4), one of the most notable examples of canal engineering to be found on this continent. This canal (Pl. VI, figs. 2 and 4) is notable both for its size and for the excellent and enduring character of its construction. The temporary makeshifts which were a marked feature of the earlier irrigation works have here been discarded and in their place are enduring structures of masonry and iron. No recent work has more strongly marked the tendency toward greater durability and firmness than the works of this canal. The head gates are of iron and rubble masonry; the waste gates and regulating gates all have iron frames. The largest flume on the canal has an iron truss support, and a smaller flume is built entirely of iron—the first, it is believed, to be built in the United States. The following description of this system is taken from a paper read before the American Society of Civil Engineers soon after the work was completed:

A fine example of the present stage of canal development, and one which has been designed and constructed under the supervision of some of the best irrigating engineers, is the Bear River Canal, in Utah, which is diverted from the Bear River at a point about 3.5 miles above Collinston. This system consists essentially of a main western and main eastern canal, diverted one from either bank, while the former is divided into two principal branches, from which are taken the various laterals supplying the private ditches. At present there are completed the diversion weir and the first 6 to 8 miles of heavy rock in the canyon which brings the water to the level of the broad valley lands which it is intended to irrigate.

The average minimum discharge of Bear River at the weir site is about 1,000 second-feet, occurring in midsummer, while the maximum recorded flood discharge is less than 9,000 second-feet. The diversion weir is admirably located between two high rock abutments and with shallow rock foundation. It is constructed of crib work filled with earth and loose stone, having a total height of 16.5 feet and a length at the bottom parallel to the channel of the stream of 38 feet, its length between abutments being 370 feet on the crest. The upstream slope is 1 on 2 and the downstream slope about 1 on ½, the water falling on a wooden apron anchored to the bed rock. All timber is 10 by 12 inches and is driftbolted to the rock bed. The head gates on the west side consist of five gates, each 4 feet wide by 7 feet high, of iron, and built into substantial masonry-in-cement abutments and piers founded on rock. The head gates to the eastern side canal are of essentially similar form of construction.

The first 2 miles of the east side canal are in heavy rockwork, in which are two tunnels, the first being 423 feet long and the second 200 feet in length. (Pl. VI, fig. 3). In this portion of the canal are a number of deep rock cuts, as shown in the accompanying

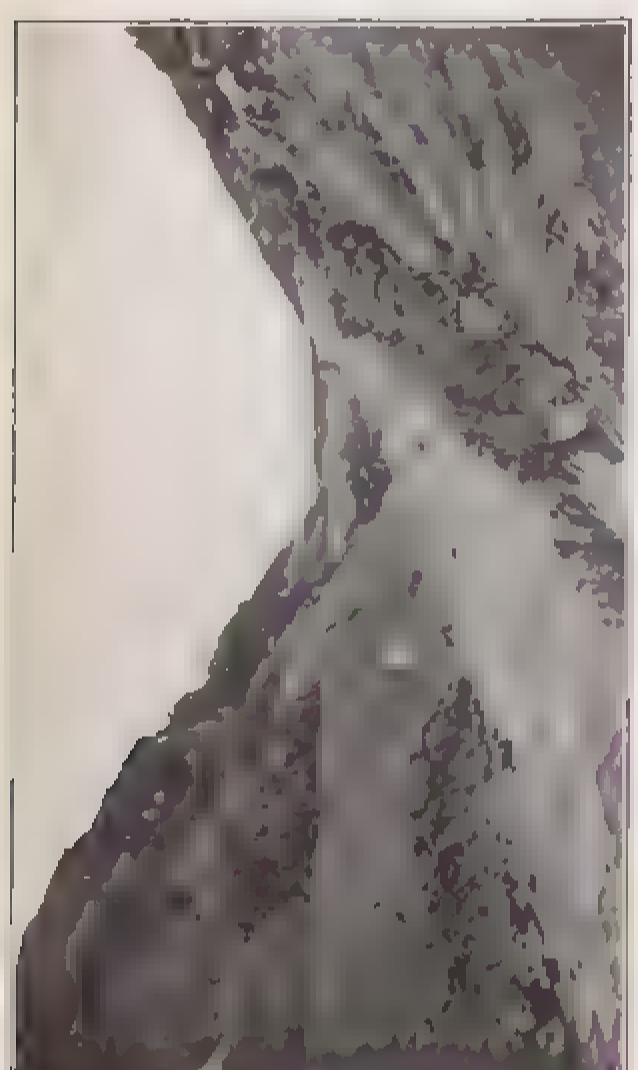


FIG. 1. BEAR RIVER CANYON, UTAH.

FIG. 2. PLANK FLUME ON BEAR RIVER CANAL.

FIG. 3. TUNNELS AND RETAINING WALLS ON BEAR RIVER CANAL.

FIG. 4. FLUME ACROSS MALAD RIVER, BEAR RIVER CANAL.

ROCK CUT 97 FEET DEEP, BEAR RIVER CANAL.

ROCK CUT 97 FEET DEEP, BEAR RIVER CANAL.

TUNNEL AND WASTEWEIR, BEAR RIVER CANAL.

FIG. 1.—BEAR RIVER CANAL, LOOKING NORTH, SHOWING DROP.

FIG. 2.—IRON FLUME ACROSS MALAD RIVER, BEAR RIVER CANAL.

ond, or miner's inch, resulted in an irrigator claiming an amount equal to the volume of the river for the irrigation of a few acres, while his neighbor might claim but a small quantity for watering 160 acres or more. The error in this particular was, however, generally on the safe side for the irrigator, and the claims on Bear River alone call for over 1,000 cubic feet per second. This volume is between three and four times as much as is needed for all the land irrigated along Bear River in Wyoming to-day.

In the Territorial adjudications, made by the courts, the carrying capacity of the ditch, instead of the area irrigated, determined the amount of the appropriation. This influenced somewhat the building of ditches as well as the form of the claims filed for record.

The State law, which has been in force since 1890, provides for a board of control, which has entire charge and supervision of the water of the State and makes all adjudications. It is made up of the State engineer and four division superintendents. The law required the county clerks to furnish the State engineer with a complete transcript of all territorial claims to water, and made the State engineer's office the place of record of all claims to water. The applications for permit under the State law correspond somewhat with the statement of claim under the Territorial law. In addition to giving the name of the owner, the dimensions of the ditch, etc., it includes a description and area of the land to be irrigated. No specific quantity of water is claimed. The application must be filed before construction is begun, and the State engineer has authority to return the paper, or map accompanying it, for correction, and to refuse permits where streams are fully appropriated. Neither the application nor the statement of claim is a title to water. Under the Territorial laws, the decree of the court was as near a title as the irrigator was able to obtain. Under the State law, the board of control issues certificates of appropriation, after the adjudication is made, which are similar to a land title and as explicit.

Under State and Territorial claims 19,840 acres of land are irrigated in Wyoming from the water of Bear River. If the State should adjudicate these rights, 283 cubic feet of water per second would be allotted to this area. The gaugings made in September, 1898, when the river was at extreme low-water stage, show the scarcity of water that would exist even if the quantities used were limited to 1 cubic foot of water per second for each 70 acres, as required by the State law. But 57 cubic feet of water per second entered Wyoming from Utah at that time. No tributary adds to this discharge until Smith's Fork is reached, which is practically on the Wyoming-Idaho line.

The tables following, taken from the State and Territorial records, give evidence of the gradual improvement in the form of the papers filed.

As before stated, only the largest ditches are shown on the map of the river (Frontispiece). The number of individual ditches is far greater. Only since 1881 have the laws of Idaho required the recording of

ditches. Utah has required it only since 1897. In neither of these States does a failure to record appropriations made prior to those years work a forfeiture of rights. Hence their records are incomplete, and the names of claimants and the amount of water claimed can not be given.

Abstract of Territorial claims to water from Bear River and tributaries in Wyoming, recorded in the office of the State engineer at Cheyenne, Wyo.

Date of instrument.	By whom signed.	Dimensions. Length.	Width. Top.	Width. Bottom.	Width. Mean.	Depth.	Amount claimed.
			Feet.	*Feet.*	*Feet.*	*Feet.*	
	John N. McElmore						
Dec. 19, 1871	David D. Colton	25,950 feet	3	2		8	720 miner's inches.
Apr. 4, 1874	Jno. W. Kerr et al						
Mar. 28, 1877	Orlando North et al						
July 8, 1878	do						
Aug. 5, 1879	Chas. Crocker et al	5 miles			2		
	John Slater						
May 6, 1881	Isaac Groo						
	O. E. Snyder						
	Anthony V. Quinn et al.				25	2	
July 11, 1881	Jas. Smith et al						
	Wm. P. Nee						
May 5, 1882	Jno. Fielding						200 miner's inches.
Apr. 12, 1892	Brigham Barnes	½ mile	2	1½		1	1 cubic foot per second.
June 13, 1891	John Burden	1 mile	8	5		2	5½ cubic feet per second.
July 1, 1891	John B. Wilson	1,000 yards	4½	3		1	1½ cubic foot per second.
May 15, 1882	Geo. Acocks						
May 22, 1882	Jno. M. Fife				3	1	500 inches.
May 27, 1882	do						
June 2, 1882	Frank Conway						1,000 cubic inches.
Apr. 7, 1882	Wm. Spence	2 miles			3	1	100 cubic inches.
June 21, 1882	Jno. B. Wilson						
Oct. 17, 1882	Stephen A. Mills et al.	4 miles			12	2	
Oct. 30, 1882	Chas. Deloney et al						
Mar. 17, 1883	Reuben Fowkes						
Mar. 20, 1883	Stephen R. Glasscock.						
May 24, 1883	Amos Edwards						
July 19, 1883	James Bowns et al	2 miles			5	3	
July 28, 1883	Wm. Cook et al	10,054 feet			20	2	
Oct. 8, 1883	Arthur W. Sims				4	2	
May 30, 1884	Alonzo F. Sights	4 miles			20	2	
July 25, 1884	G. Christensen	1¾ miles			3	2	
Aug. 4, 1884	Martin Christensen	500 yards			4	2	
Sept. 1, 1884	James Blight				5	3	
Jan. 16, 1885	G. Christensen	2 miles			3	1	
Nov. 5, 1884	Wm. Morris et al	3½ miles			8	2	
July 2, 1885	Wm. H. Lee	2 miles			10	3	
Aug 24, 1885	Cramer Deuel				10	2	
Oct. 20, 1885	W. H. Blanchard	1½ miles			4	1½	
Dec. 18, 1885	John Felter				2	1	
Feb. 27, 1886	Jean Pierre Anel	½ mile			3	3	
Mar. 19, 1886	Alfred A. Mott				2	½	
Mar. 25, 1886	Chambers & Whitney.	20½ miles			8	3	
Apr. 12, 1886	A. Brown				3	2	
May 8, 1886	Thomas Baker				3	2	
May 15, 1886	Wm. Brown	1½ miles			3	1	
Do.	Enoch Turner et al.	½ mile			4	1	
May 19, 1886	Wm. Brown et al	1½ miles			3	1	
May 25, 1886	Arthur W. Sims				3	1	
May 20, 1886	Mary M. Sights				6	1½	
July 20, 1886	Reuben Fowkes				6	1½	
July 27, 1886	James McMahon	2 miles			2	1	
Aug. 7, 1886	John A. McGraw	1 mile			7	1½	7 cubic feet per second.
Aug. 13, 1886	Geo. F. Chapman et al.	7 miles	15	12		3½ 1	
Aug. 17, 1886	Saml. Knoder	1 mile	5	4			
Aug. 23, 1886	Jno. H. Whitney	9 miles			5½	1½	
Aug. 30, 1886	Luke Morris et al	500 feet	4½	3½		1½	3 cubic feet per second.
Aug. 31, 1886	June Reese	300 yards	4	3		1½	2.625 cubic feet per second.

***Abstract of Territorial claims to water from Bear River, etc.*—Continued.**

Date of instrument.	By whom signed.	Dimensions. Length	Width. Top.	Width. Bottom.	Width. Mean.	Depth.	Amount claimed.
			Feet.	*Feet.*	*Feet.*	*Feet.*	
Sept 1, 1886	Chas. M. White	11 miles			10	2½	12 cubic feet per second.
Do	A. C. Beckwith et al.	5 miles	18	15		1½	8.333 cubic feet per second.
Do	do	10 miles	22	18		2½	20.833 cubic feet per second
Sept 2, 1886	Jno. W. Myers	1½ miles	5	4		1	7.65 cubic feet per second.
Sept. 22, 1886	Jno. Wagstaff	2½ miles	3	2		1	5 cubic feet per second.
Oct. 18, 1886	John Fearn	200 yards	2	1½		1	1,487 cubic inches.
Sept. 23, 1886	H. H. Cook	4 miles	20	16		2	15 cubic feet per second.
Mar 14, 1887	Jos. W. Cook						
June 22, 1887	H. N. Bodine et al	1½ miles	6	4		2	10 cubic feet per second.
June 11, 1887	Wm. H. Wyman	1 mile	20	16		2	6.5 cubic feet per second.
Do	do	do	18	14		2	Do.
Oct. 13, 1887	Jno. B. Wilson	1½ miles	3	2		1	2.5 cubic feet per second.
Mar 8, 1888	Jno. A. Holmes	2 miles	5	4		1	4.5 cubic feet per second
Mar. 30, 1888	Geo. F. Chapman	8 miles	16	14		2	61.20 cubic feet per second.
Apr. 2, 1888	Jno. M. Sights	1 mile	2½	1½		1	2 cubic feet per second.
June 9, 1888	Richard Irwin	1½ miles	7	5		2	12 cubic feet per second
May 9, 1888	do	1½ miles	2½	1½		1	4 cubic feet per second.
May 28, 1888	Frederick Coles	¾ mile	4	3		1	3½ cubic feet per second.
June 23, 1888	Robt. M. Lewis	¼ mile	6	4		1½	7.5 cubic feet per second
Sept 3, 1888	J. N. Whitney	2 miles	6	6		2	100 cubic inches.
Oct. 4, 1888	Robt. M. Lewis	1½ miles	7	5		1½	13.5 cubic feet per second.
Nov. 10, 1888	Chas. P. Pixley	2½ miles	29	18		1½	25 cubic feet per second.
Aug. 21, 1886	Wm. Hinton		2½	1½		1	864 cubic inches per second.
Aug. 20, 1886	do		4½	3½		1½	1.51 cubic feet per second.
Aug. 21, 1886	do		2½	1½		1	864 cubic inches per second.
Do	do		2	1		1	2.125 cubic feet per second
Aug. 20, 1886	do		4½	3		1½	1.125 cubic feet per second.
Aug. 21, 1886	do		5	3		2	3.333 cubic feet per second.
Jan. 24, 1889	Henry H. Stedman	1½ miles	10	8½		1	9.25 cubic feet per second.
Mar. 4, 1889	Martin V. Morse	¾ mile	20	14		1½–6	22.5 cubic feet per second.
Feb. 26, 1889	Jno. R. Bothwell						
Mar. 30, 1889	Wm. H. Byrne	½ mile	4	3		1	3.5 cubic feet per second.
Do	do	¼ mile	1	[illegible]		[illegible]	1 cubic foot per second.
Apr. 5, 1889	Jno. B. Wilson	3½ miles	5	3		1½	6 cubic feet per second.
Apr. 23, 1889	Jno. R. Richards	80 rods	4	3		2	2 cubic feet per second.
Apr. 27, 1889	Wm. Crompton	1½ miles	4	3		1½	5 cubic feet per second.
May 11, 1889	Jno. Blight	4 miles	10	6		1	9 cubic feet per second.
June 10, 1889	Jesse Knight	8,600 feet	6	5		1½	4 cubic feet per second.
July 3, 1889	Geo. T. Dunford	600 yards	1½	1		½	1 cubic foot per second.
July 8, 1889	John Fife	do	1½	1		½	½ cubic foot per second.
Aug. 5, 1889	Wm. Garrett	1½ miles	7	5		1	6 cubic feet per second.
Sept. 26, 1889	J. P. Anel	3½ miles	6	4		1½	5 cubic feet per second.
Oct. 15, 1889	Jas. B. Bruce	800 feet	4	3		1	3 cubic feet per second.
Nov. 9, 1889	Henry Homer	1½ miles	4	3		3	Do.
Dec. 2, 1889	Harvy Booth	6 miles	12	8		2	40 cubic feet per second.
Mar. 4, 1890	Wm. P. Nebeker	6½ miles	16	12		3	60 cubic feet per second.
Apr. 24, 1890	Oscar E. Snyder	1½ miles	20	16		[illegible]	8 cubic feet per second.
May 22, 1890	J. C. Jacobson	1 mile	8	6		2	14 cubic feet per second.
June 3, 1890	A. G. Richards	4 miles	2	2		1	26 cubic feet per second.
Aug. 2, 1890	John Titmus	10 miles	9	7		3	24 cubic feet per second.
Nov. 18, 1890	Bear River and Yellow Creek Irrigation and Land Co.						
Dec. 19, 1890	Robt. M. Lewis	4½ miles	6	5		1½	14.5 cubic feet per second.
Feb. 6, 1891	Wm. Hinton	20 miles	30	16		2½	100 cubic feet per second.
Mar. 9, 1891	Geo. Tibbets	2½ miles	5	4		1	

Abstract of the permits to appropriate water from Bear River and tributaries issued by the State engineer of Wyoming since January 1, 1891.

Date of instrument.	By whom signed.	Dimensions. Length.	Width. Top.	Width. Bottom.	Depth.	Acres irrigated.
			Feet.	*Feet.*	*Feet.*	
July 2, 1891	Geo. Tschirgi	3 miles	8	6	2	1,020 acres.
Aug. 21, 1891	Jno. L. Russell	895 feet	3	2	1½	Mining.
Nov. 27, 1891	Jonathan Jones	13 miles	10	6	2	7,040 acres.
Apr. 5, 1892	W. P. Nebeker	11 miles	15	9	3	3,520 acres.
May 2, 1892	Wm. Fearn	¾ mile	2½	2	1	60 acres.
June 5, 1893	Augustus W. Anderson	7 miles	6	4	1½	440 acres.
Aug. 28, 1893	I. C. Winslow	10 miles	7½	6½	3	
Aug. 1, 1895	John Felter	2¼ miles	5	3	2	320 acres.
Jan. 13, 1896	Jno. Cunnington, sr	2,400 feet	3	2	1	85 acres.
July 13, 1895	Sarah Ann Faulkner	1.05 miles	3	2½	1	Do.
Feb. 6, 1896	Wm. C. Cunnin ton	1 mile	3	2	1	200 acres.
May 14, 1896	Geo. Durnford, jr	¼ mile	4	3	1	85 acres.
May 18, 1896	John Bruce	½ mile	4	3	1	55 acres.
Nov. 2, 1896	Laban Heward	1½ miles	4	3	1	66 acres.
Mar. 20, 1897	Wm. Longdon	¾ mile	5	4	2	40 acres.
May 31, 1897	Zebulon P. Dickey et al	8 miles	8	6	2	1,280 acres.
July 12, 1897	John A. McGraw	700 feet	8	7	1	440 acres.
Sept. 9, 1897	Thos. S. Johnston	1 mile	2	1½	1	90 acres.
May 24, 1897	Mattie Lyndon	¾ mile	3	2	1	7 acres.
Nov. 17, 1897	Peter Dauks	½ mile	3½	2¾	1	19 acres
Feb. 3, 1898	Jos. B. Coffman	1 mile	5	3	1	180 acres.
Feb. 19, 1892	R. C. Chambers	8½ miles	24	18	4	10,083 acres.
May 24, 1897	Chas. Todd	270 feet	1½	1	1	30 acres.
June 30, 1892	Mary Lannon	2½ miles	6	5	1	80 acres.
Aug. 31, 1897	R. C. Chambers	30 miles	36	24	6	47,080 acres.
Oct. 13, 1898	Thos. Blyth	1,284 feet	3	25	1	26 acres.
Do	do	1 mile	4	3	1½	48 acres.
June 27, 1898	Laban Heward	1½ miles	5	4	1	66 acres.
July 9, 1898	Joseph Bird	15 miles	11	7	2	2,732 acres.
May 22, 1899	Thos. Cowlishaw	7 miles	6	4	1½	300 acres.

THE IRRIGATED AND IRRIGABLE LANDS.

The area which Bear River can be made to reclaim is restricted. On the upper third of the stream the alluvial valleys along the river have nearly all been irrigated. Further extensions will require larger and costlier works and the building of ditches to irrigate land along other streams, like the projects for irrigating the Hilliard Flats and the valley of Yellow Creek. In Idaho the land which can be profitably watered is limited in extent, and much of it is too uneven in surface to be attractive to irrigators. The greatest expanse of unoccupied land and the field of future growth is in Utah. Both in Salt Lake Valley, under the Bear River Canal, and in Cache and Gentile valleys, under projected canals, there is destined to be a great increase in the cultivated area.

The following table gives a close approximation to the reclaimed and reclaimable area in each State:

Irrigated and irrigable areas in Wyoming, Utah, and Idaho.

State.	Land irrigated.	Land yet to be reclaimed.	Total capable of being irrigated.
	Acres.	*Acres.*	*Acres.*
Wyoming	19,840	23,840	43,680
Utah	56,000	207,000	263,000
Idaho	16,000	*a* 10,000	26,000
Total	91,840	240,840	332,680

a Estimated.

The scarcity experienced by the appropriators living between the head of the stream and the mouth of Smiths Fork has led to considerable uneasiness and to a desire for an interstate adjudication of priorities by appropriators below, but a study of all the conditions shows their fear of scarcity to be groundless. Smiths Fork and Logan River are the principal sources of supply, and both reenforce the stream below where the greatest use now occurs. Three hundred and thirty thousand acres is believed to embrace all the land which can be profitably watered. The mean yearly flow of the stream for the past five years has been over 1,500,000 acre-feet. This would cover to a depth of nearly 5 feet all the lands which can be irrigated. One-half that amount will be ample. The immense size of Bear Lake, and the ease and cheapness with which it can be converted into a reservoir, make it possible to utilize practically all the water discharged from the stream except that flowing from Logan River. All that is needed is its conversion into a storage basin and the building of a canal from Bear River to fill it.

The irrigators along the Wyoming and Utah boundary need relief. During the past six years there have been a number of seasons when the stream was drained as dry as it was in 1898, when only defective dams prevented a dry channel. The completion of the Hilliard Flats or Yellow Creek Canal will either rob existing users below or lead to some sort of an agreement for the establishment and enforcement of priorities across State lines. The problems which will have to be solved before an interstate settlement of priorities can be had will be discussed in the succeeding pages of this bulletin.

INTERSTATE WATER RIGHTS IN BEAR RIVER.

By Joseph A. Breckons.

INTRODUCTION.

IMPORTANCE OF IRRIGATION.

The agricultural interests of fifteen States and Territories of the West depend directly and almost entirely upon irrigation and irrigation methods. These States and Territories (California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, North Dakota, South Dakota, Utah, Oregon, Wyoming, Arizona, New Mexico, and Oklahoma) comprise an area of 1,465,000 square miles, almost one half the area of the United States, and support a population of nearly six millions of people.

To the agricultural interests may be added the live-stock interests of these States and Territories, for, almost universally in the West, the live-stock interests are becoming merged with those of agriculture. Indirectly all of the great commercial interests of this vast region—great enough in extent, variety of resources, and population to be well termed an empire—are dependent upon the successful application of irrigation.

In this vast empire of the West water is the one essential element of all productiveness and consequent prosperity. Its use for mining operations first attracted attention, and was the subject of such legislation as made it applicable to mining matters. Its use for agricultural purposes of every kind has become far more important and beneficial, and more closely connected with the welfare of the communities of the West. Regions which were sterile and barren have, with the application of irrigation, been turned into gardens and made to blossom as the rose. Other regions, great in area and in latent possibilities, await the awakening touch of the magical, life-giving waters. The fountain of perpetual youth, in search of which the romantic Spaniard gave up his life when the century was young, has been found by the practical agriculturist of the West, and the dead plains and deserts, the barren valleys, the uplands and hillsides, for centuries covered with the shroud of sagebrush and greasewood, are now alive with the beneficent fruits made possible by the life-giving waters.

While wonders have been worked in the desert places of the West by means of irrigation, the results are infinitesimal compared with what remains to be accomplished by the full and complete utilization of the

resources which nature has placed at our disposal. The results already obtained have been secured by haphazard methods, lacking in uniformity and system. No interest of the West should be fostered by more careful legislation, based upon full and accurate information of conditions; yet none has more uncertain, unsettled, or unsatisfactory laws. The interests of the agriculturists of the West are in the main similar, and yet laws and methods relating to irrigation are as diverse in character in adjoining States as if the two Commonwealths were on different sides of the globe. The subject demands careful and complete legislation, which shall define the rights of all interested parties and establish a code of rules regulating them upon a comprehensive and just basis, and which shall establish uniformity in all of the irrigated region of the continent without reference to the artificial lines of State boundaries.

INTERSTATE CONTROVERSIES.

Under the present diverse treatment of irrigation matters by the several States and Territories of the irrigation region, the lack of legislation in one State, the radical difference between neighboring States in determining and adjudicating water rights, the too liberal appropriation of waters by some, and the general tendency of the residents of one State to disregard the rights of the citizens of another, all tend toward preventing the full utilization of the waters of the West, and toward depriving countless citizens of the full enjoyment of rights which, under a proper adjustment, they could have without prejudice to others.

This is not a theory, but an unfortunate condition obtaining in many portions of the West. Hundreds of streams have users of water on different sides of State lines, and the rights of the residents of one or the other of these States are frequently infringed by their neighbors across the State line. A recourse to the courts in such cases is expensive and troublesome and the litigation complex and lengthy. It can readily be seen what endless confusion would result were methods of determining land ownership, or ownership of personal property, placed upon such an uncertain and shifting footing as is the ownership of water. Uniform laws and similar methods determine all rights of real and personal property. The land laws of the several States are national and general in character, while in the West, for the waters which make these lands valuable, methods for the determination of water ownership and rights are widely different across State lines. Some States have elaborate systems of irrigation legislation, while others are almost devoid of legislation upon the subject.

NEED OF UNIFORM IRRIGATION LAWS.

The situation is, however, not wholly discouraging. Irrigation is yet in its primitive state in many portions of the West. It has been

an experiment and has not settled into definite lines that can not be changed. The chaos that exists is not an unmixed evil, in that it is so apparent that reform is suggested by its prominence. The value of water is becoming so apparent to all that none disputes the desirability of utilizing the full capacity of every stream, river, lake, and water course. All are beginning to recognize that this can only be effected by uniform legislation, by the accurate determination of the greatest duty of water, by its fair division, by the selection of suitable crops for certain altitudes, latitudes, and longitudes—in short, by making irrigation an exact science and by protecting all of its beneficiaries by uniform and just laws.

When this is accomplished the full beneficial use of the water and land of the West will have been secured and the rights of the people to both will be protected; litigation over irrigation rights, now threatening to overrun the courts, will be reduced to a minimum, and interstate quarrels, now imminent, will have their cause removed. Such a consummation is a possibility. The same general principles underlie and apply to the use of water for irrigation purposes in all parts of the West. Right to the use of water by virtue of prior appropriation and the necessity of devoting water to beneficial uses in order to obtain ownership are generally recognized as underlying principles of irrigation law in the West, and it needs but uniformity of legislation, uniformity of executive methods, and uniformity of details of procedure in acquiring water ownership to secure equality of rights and the full utilization of the resources provided by nature.

ABROGATION OF RIPARIAN RIGHTS.

It was early determined in the West that the common-law doctrine concerning the use of water of natural sources which had been recognized and enforced by the courts both in this country and in England for centuries was not applicable to conditions where either mining or agriculture by irrigation formed the chief industries. The common-law doctrine is that the water of permanent running streams and of inland lakes is sacred to the common use alike of all riparian proprietors upon their borders. The doctrine extends to navigable and unnavigable streams and lakes which are wholly inland and territorial. Under this doctrine each proprietor may use the water for all reasonable purposes as it passes through or by his land, but he must, after its use, return it without substantial diminution in quantity or change in quality to its bed or channel before it leaves his own land, so that it will reach his adjacent proprietor in its full, original, and natural condition. Priority of use or appropriation by any one proprietor can give him, under this doctrine, no higher or more extensive rights than these. He has no property in the water itself, but simply the use of it while it passes along. He can not detain it or give it another direction, and he must *return it to* its ordinary channel when it leaves his estate.

ORIGIN OF THE DOCTRINE OF APPROPRIATION.

The common-law doctrine, if applied to mining and irrigation, would almost wholly preclude these pursuits. This was recognized in the early history of the mining camps in the placer regions of California. Remote from the operations of law, customs and usages in reference to water, wholly at variance with the venerable tradition of the common law, came into use, and were adopted and enforced with rigor by the miners. They had thus a distinct creation, although, unknown to these people, a precedent existed in the old Roman law, which in all irrigated regions did not recognize the doctrine of riparian rights. The legislature of California in 1851 gave to these usages and regulations legal efficacy by enacting that "the customs, usages, or regulations, established or in force at the bar or diggings embracing said claims, and such customs, usages, or regulations when not in conflict with the constitution and laws of this State, shall govern the decision of the action." These mining customs or rules were simple, and related to the acquisition of "claims" to mineral land and to water for the purpose of mining, and prescribed the acts necessary to constitute such an appropriation of a parcel of mineral land or portion of a stream as should give the claimant a prior right against all others. In this is the origin of the doctrine of water rights as settled in the Western communities. Water was an indispensable requisite for carrying on mining operations; a permanent right to use certain amounts of water was as essential as the permanent right to occupy a certain parcel of mineral land. The streams and lakes were all on the public domain. It was often necessary to divert water from its natural bed or course. From all these circumstances, and from the very necessities of the situation, it became one of the mining customs or regulations that the right to use a definite quantity of water, and to divert it if necessary from these streams and lakes, could be acquired by appropriation.

This custom was soon approved by the courts, and the doctrine became settled in the Western States, in opposition to the common law, that a permanent property in the water of streams and inland lakes upon the public lands of the United States may be acquired for mining purposes by mere appropriation; that an appropriator may thus acquire the right to divert, use, and consume a quantity of water from the natural flow of streams which may be necessary for the purposes of his mining operations; and that he becomes, so far as he has thus made an actual appropriation, the owner of the water against all the world except the United States Government. This doctrine, applied at first to the operations of mining, was found equally applicable to agricultural interests, and has been extended to this and all other beneficial purposes for which water may be essential.

The right of property in water thus settled by the State courts availed

against all persons excepting the United States Government. This limitation was soon removed. Congress, by the act of July 26, 1866, recognized a right to water on the public domain, acquired by prior appropriation, as a substantial and valid right which the Government was bound to acknowledge and protect. The statute has been held by the United States Supreme Court to be "a voluntary recognition of a preexisting right of possession, constituting a valid claim to its continued use."

PRINCIPLES WHICH GOVERN APPROPRIATIONS OF WATER.

From the foregoing it may therefore be stated that the principles governing the use of water may be briefly summed up as follows: While a natural stream or lake is situated on the public lands of the United States, within the limits of a State, a person may, under the customs and laws of a State and the legislation of Congress, acquire by appropriation the right to use the waters thereof for beneficial uses, and to construct reservoirs and ditches over and upon the public land. When such a right has been acquired by prior appropriation, subsequent grantees of the public domain bordering upon the same stream or lake, homestead settlers and all other purchasers, take and hold their titles subject thereto.

Upon this basis there may be built, by the exercise of intelligent and practical action, a comprehensive system of exact irrigation juris prudence applicable to the entire area of the West in which irrigation is a necessity or benefit. With this principle kept in view before the regulations and methods of the several States become irrevocably fixed, there may be established uniformity in methods of appropriation; uniformity in the executive administration of water laws; customs, now conflicting in neighboring States, may be harmonized; a general and equitable standard of the duty of water established, and irrigation laws, instead of varying with every arid commonwealth, may be as uniform, simple, and as easily understood as those governing the ownership of land.

INTERSTATE WATER RIGHT CONTROVERSIES.

The controversies which already exist between the water users of adjoining States are many, and with the continuous increase in the use of water these controversies bid fair to become so numerous as to burden the courts with their settlement. Controversies of this nature now exist between citizens of Wyoming and Nebraska, Wyoming and Colorado, Wyoming and Utah, Wyoming and Idaho, Wyoming and Montana, Colorado and Kansas, Colorado and New Mexico, and in fact between the citizens of all contiguous States and Territories in the irrigated regions of the West.

These controversies are assuming State importance. The last Wyoming legislature appropriated funds to sustain a suit against Colorado

appropriators of water from streams flowing from Colorado into Wyoming, which it is claimed they are unlawfully diverting. The last legislature of Kansas authorized the counties of that State to appropriate funds to protect in the courts the rights of Kansas irrigators to the water of streams flowing into Kansas from Colorado. The Territorial legislature of New Mexico has appointed a commission to investigate the question of water supply for irrigation purposes, with a view to protecting the interests of the irrigators of New Mexico.

To take up and discuss this endless list of controversies in all of the diverse conditions of the different interstate flowing streams would make a bulletin too complex for general use or information. One stream only will therefore be discussed, and one has been selected which presents within itself examples of these controversies in concrete form. This is the Bear River, a stream which rises in Utah, crosses the southwest corner of Wyoming, returns to Utah, returns again to Wyoming, leaves Wyoming and enters Idaho, where it makes an abrupt loop, returning again to Utah, where it empties into Great Salt Lake at a point but little over 100 miles from its source.

In all of the States traversed by this river the settlers along its course are drawing on a common source for water for irrigation purposes; in all is recognized the doctrine of the right to use of water by virtue of prior appropriation, and the settlers are calling upon their respective commonwealths to protect that right. Yet, because these rights have thus far been left to the settlement of State tribunals which only exercise jurisdiction within State boundaries and have no influence beyond, over 250 distinct appropriations, one representing an outlay of $1,000,000, are as absolutely without specific regulation as if there were no irrigation laws. And while it is true that the courts may in time be invoked in litigation, yet a decision regarding priorities across State lines will not open head gates across State lines when the stream rises enough to give water for all or close them when water is scarce. That needs an officer with specific duties. It would be just as easy to conduct a city water plant without an engineer to run the pump as to try to enforce priorities across State lines without some authorized official to open and close gates. There is now no United States or State law to correct this need.

Some Wyoming irrigators along the stream have taken advantage of these conditions, and in order to avoid the enforcement of priorities in Wyoming have built the head gates of their ditches just across the State line in Utah.

DIFFERENCE BETWEEN WATER-RIGHT RECORDS IN STATES CONCERNED.

A great many of the irrigators who are taking water from this stream and experiencing this unsatisfactory condition of affairs have called for a remedy, and have urged a division and adjudication of the

waters of the entire stream. But when authority is sought to make such a study of the stream as is necessary for such a division and adjudication it is found that there must be some legislation to bring the rights of the irrigators and the methods of enforcing them into harmony.

Some perplexing problems will have to be solved before such division and adjudication as suggested can be effected. All agree that priority of appropriation and devotion of water so appropriated to beneficial use establishes the right of the appropriator. But before there can be any division of the waters on a just basis it must be known when and how the rights of the individual appropriators were acquired.

In commencing to make such division the following situation would be confronted:

In Wyoming certain requirements in reference to recording ditches are observed. An examination of the official records of a body established by State law and known as the State board of control will disclose the date of appropriation, the object, and the amount of water to which the appropriator is entitled.

In Utah there is no general record of such rights and no common place of record. Whatever records there are in Utah of rights acquired prior to the passage of the law of 1897 are voluntary ones, made by appropriators with county officers. There is no examination by authorized officials to determine if the records are in accord with facts, and such records as are made do not always give a correct and complete history of the existing situation. The Utah records of the Bear River appropriations are scattered among four counties, and in order to determine the status of contiguous water users at various places on the stream all of the four county seats must be visited.

The second State legislature of Utah passed an act requiring that all persons intending to construct irrigation works must post a notice at the head gate and record a statement of claim in the office of the county clerk. The same act also provides for the recording of claims existing at the time of its passage. This clause was made inoperative by the following proviso: "That a failure to comply with the requirements of this section shall in no wise work a forfeiture of such heretofore acquired rights or prevent any such claimant from establishing such rights in the courts." By reference to the map it may be seen that even though the records of Utah were faithfully kept they would do no good above Bear Lake, because Idaho intervenes.

In Idaho the situation is somewhat similar to that in Utah. The records of appropriations are in the several counties and are subject to no general rule as to form and method of keeping. The recorded claims differ in various counties as to the unit of measure employed, and the amount of water claimed depends largely upon the desires of the claimant. There is no system of adjudication or record employed in the State, and there is general complaint that no one can enjoy the

ownership of water sufficient to render his farm permanently productive until his rights have been tested by lawsuits. The records become encumbered with imperfect water-right locations, many of the papers recorded failing to state necessary facts to constitute an intelligible record. The records, being in the various county seats, are widely scattered, and the failure to require any submission of proof of compliance with the law after the recording of the notices of claim renders the records useless for the purpose of determination of perfected appropriations.

DIFFERENCE IN CHARACTER OF RIGHTS.

It may therefore be readily seen that at the outset the claims of appropriators of water from the Bear River on record could not be taken as a basis for the equitable division of its waters.

If an effort should be made to go further and to determine what the actual rights of the people are who are using the waters of the stream, the first step would be the establishment of a standard by which these rights might be measured. If a right be determined by the size of the ditch built by the Idaho appropriator, this should also determine the rights of the appropriators in the other two States. If it is determined in Wyoming by the acreage which has been irrigated, or the needs of that acreage, the same standard should be employed in Idaho and Utah. There could never be a harmonious and just division of the waters of the stream across State lines, no matter by what authority divided, if in Wyoming rights should continue to be measured by the acreage irrigated, and in Idaho and Utah such rights should be measured by the size of the ditch whether any acreage is irrigated or not. As a matter of fact, an examination of the irrigation statutes of these three States will show that the laws of Wyoming do not recognize any but usufructory rights, and the water appropriated for irrigation is measured by the acreage upon which it is to be used and the necessities of that acreage. While not settled by the courts of last resort of the State, so far as the administration of the irrigation laws is concerned ownership of water is held to be inseparable from that of the land to which it appertains. In Utah rights to water can be acquired for purposes of sale, and water is declared by statute to be personal property. The courts of the State have held that water ownership can be separated from land ownership, and thus it is made a separate or floating right. In Idaho there has been no settlement of these matters, and there is no degree of certainty as to what a water right really is, or whether once acquired it is attachable to any part of the land it is desired to water, or is movable at will up or down stream.

DIFFERENCE IN TRIBUNALS WHICH DETERMINE RIGHTS.

If an attempt should be made to divide the waters of the Bear River equitably, regardless of State boundary lines and upon a common standard of measurement, such division would have to be made by a

tribunal which should establish and adjudicate the various rights in accordance with the laws of the respective States through and in which the waters of the stream flow. Could such a tribunal be agreed upon is a doubtful question.

In Wyoming the executive authority for dividing and adjudicating the waters of the river is the State board of control, a member of which collects the testimony of all who use the waters of the stream, obtaining facts as to dates of construction of ditches, size of ditches, time of first appropriation by each user, and acreage irrigated by each, and the waters are divided as equitably as may be possible with this information as the basis for making the division.

In Utah there is no tribunal by which the waters of the stream may be divided other than the courts, and rights are determined by an ordinary suit at law between claimants.

In Idaho, if a dispute arises, the courts must be appealed to for a division of water among irrigators.

In order to effect a satisfactory division, the tribunal making it must meet the ideas and prejudices of the people to be governed by its decisions, and in all the steps to be effected their views must be conformed to in as large a degree as possible. With the records of priorities and amounts of appropriations at hand, and with a uniform standard of measurement established, the question still remains: Is it feasible to get the people of the several States to agree upon any uniform method of supervision?

As conditions now exist, with water users working out these various problems within the borders of their own States, and the methods and forms of procedure of these States far apart in irrigation matters, the efforts to draw them closer together will necessarily work injury to some individuals. The number injured, however, will certainly be smaller if the efforts are made in the immediate future than if put off to some distant date.

EVILS OF LITIGATION OVER WATER RIGHTS.

No case involving contests between residents of adjoining States for the right to use the waters of a stream flowing in or through both States has as yet reached ultimate and final decision in the courts. This is due in a measure to the fact that such litigation is extremely expensive, tedious, and vexatious, involving a final appeal to the United States Supreme Court; that the pioneers in irrigation have been generally settlers of small means, who have preferred submitting to injustice rather than become involved in legal controversies likely to absorb a goodly portion of their belongings; and that the absence of irrigation laws in many of the irrigated States has given license to might rather than right in the settlement of water-rights controversies. Even States the interests of whose citizens have been encroached upon by the citizens of adjoining States have been slow to plunge into legal controversies, and have allowed their citizens to suffer without an effort to afford them the protection to which they should be entitled.

This state of affairs, it is self-evident, can not continue much longer. The rapidly increasing importance of irrigation interests, the necessity of securing the greatest service from the waters of all streams, and the need of protection for vested rights, all tend to make it imperative that a remedy must soon be found either in the courts or in the State or National legislatures.

CASE OF HOWELL v. JOHNSON.

The extent to which settlement of interstate rights to water has been reached by the courts is found in the case of Howell *v.* Johnson et al. (89 Fed., 556), in which a decision was recently rendered in the United States circuit court for the district of Montana by Hon. Hiram Knowles, district judge.

The decision is as follows:

The plaintiff is a citizen of the State of Wyoming. The defendants are all citizens of the State of Montana. In his bill of complaint the plaintiff sets forth that he is the owner of certain lands in the State of Wyoming, and that, for the purposes of irrigating the same, he appropriated certain waters of a creek called "Sage Creek." This creek has its sources in Montana, and flows for some distance within its boundaries before it enters the State of Wyoming. Plaintiff's ditch and point of diversion of said waters are both within the last-named State. Defendants settled along the line of said creek, in Montana, subsequent to the appropriation of plaintiff, and in said State have diverted, it is alleged, the waters of the said creek, and prevented the same from flowing down to plaintiff's ditch and land. Plaintiff has sued defendants in this court, and asks to have them enjoined from so diverting said waters. Defendants have filed a demurrer to this bill.

The points presented in this demurrer are that plaintiff, having a water right acquired under and by virtue of the laws of Wyoming, can not come into this court to enforce the same. It is also claimed that the rights pertaining to this water are under the control of the legislative power of Montana.

Considering the first point, it is urged that the right of plaintiff, being acquired under and by virtue of the laws of the State of Wyoming, can be enforced only as to citizens of Wyoming, and not against citizens of Montana, who have diverted water only in Montana. Is the right claimed by plaintiff one which accrues only by virtue of the laws of Wyoming? Plaintiff alleges that he made his appropriation of the waters of said creek in accordance with the laws of Wyoming and Montana. Allowing that there could be no appropriation of the waters of said creek made in Wyoming under or by virtue of the laws of Montana, still the allegation that the appropriation was made under the laws of Wyoming remains. According to the bill plaintiff's appropriation was made on the 1st day of August, 1890. At that date sections 2339 and 2340 of the Revised Statutes were in force. They provided:

"Whenever, by priority of possession, rights to the use of water for mining, agricultural, manufacturing, or other purposes, have vested and accrued, and the same are recognized and acknowledged by the local customs, laws, and the decisions of courts, the possessors and owners of such vested rights shall be maintained and protected in the same; and the right of way for the construction of ditches and canals for the purposes herein specified is acknowledged and confirmed; but whenever any person, in the construction of any ditch or canal, injures or damages the possession of any settler on the public domain, the party committing such injury or damage shall be liable to the party injured for such injury or damage. All patents granted, or preemption or homesteads allowed, shall be subject to any vested and accrued water rights, or rights to ditches and reservoirs used in connection with such water rights, as may have been acquired under or recognized by the preceding section."

In the case of Basey v. Gallagher (20 Wall., 670), the Supreme Court said in regard to this act: "The act of Congress of 1866 recognized the right to water by prior appropriation for agricultural and manufacturing purposes as well as mining;" and also decided that if the right to appropriate water for any of the purposes named was recognized by either local customs, or by the legislation of any State or Territory, or by the decisions of the court, it would be sufficient. The allegation in the bill that the water was appropriated under the laws of the State of Wyoming would meet the requirements of the said act of Congress. Up to the passage of the said act of 1866, the right of the prior appropriator to use water, for any of the purposes above named, had, in the arid and mining regions of the West, been recognized as against any other person claiming the same, but not as against the National Government. This act, coupled with the act of July 9, 1870, embodied in said section 2340, recognized the right of the prior appropriator of water upon the public domain, even as against the United States and its grantees, if said appropriation was authorized by the statute of the State where the appropriation was made. (Black's Pom. Water Rights, No. 25; Osgood v. Mining Co., 56 Cal., 571.) The rights of the plaintiff do not, therefore, rest upon the laws of Wyoming, but upon the laws of Congress.

The legislative enactment of Wyoming was only a condition which brought the law of Congress into force. The National Government is the proprietor and owner of all the land in Wyoming and Montana which it has not sold or granted to some one competent to take and hold the same. Being the owner of these lands, it has the power to sell or dispose of any estate therein or any part thereof. The water in an unnavigable stream flowing over the public domain is a part thereof, and the National Government can sell or grant the same, or the use thereof, separate from the rest of the estate, under such conditions as may to it seem proper.

In Black's Pom. Water Rights, No. 32, it is said:

"As the Federal Government, in conveying any particular portion of its public domain within a State to a particular grantor, may, as proprietor, annex any condition to the conveyance so that the title will be taken and held subject thereto, so it may, by Congressional legislation, adopt any general conditions upon the use of the public domain to all persons, or upon all persons, who acquire title to portions of the public domain from the Government, and the title so acquired will be held by the grantees thereof, subject to such conditions and limitations. Thus, Congress may provide by general statute for a right of way over the public lands unsold for the ditches and canals of those who have made a prior appropriation of water, and that all grantees who subsequently acquire portions of this land shall take and hold their titles subject to such existing right of way, or that all grantees of public lands bordering upon a stream shall take and hold their titles subject to any previously existing appropriation of its waters."

These views are supported by the case of Mining Co. v. Ferris, 2 Sawy., 176, Fed. Cas. No. 14371.

The Federal Government is not restrained in the disposal of its lands by State laws or State lines. Its laws upon this subject apply to the lands in one State as well as another. It has made grants of land extending through several States. The State governments can not restrict it in the primary disposal of its lands. If it may sell and dispose of its land as it may deem proper, there is no reason why it may not sell a part thereof as incident thereto, such as the use of water flowing over the same. That it has the same right as any real estate proprietor would be self-evident. It is apparent, then, according to the allegations of the bill, that plaintiff acquired rights by appropriation in Sage Creek to which all who have acquired lands upon the same, or water rights therein, subject to his appropriation, must be subordinate. His rights have the sanction of the Federal Government.

It is urged that in some way the State of Montana has some right in these waters in Sage Creek or some control over the same. It never purchased them; it never owned them. In support of this view, the court is cited to a great many decisions which apply to navigable rivers and lakes and tide waters. Here we approach a

different subject. There is no claim that Sage Creek is a navigable stream. A State, upon its admission into the Union, acquires, by virtue of its sovereign powers, the title to the beds of all navigable rivers, lakes, and tide waters within its boundaries, subject, however, to its rights of commerce and navigation. This title gives it, to some extent, a control over the waters of such rivers and lakes and the power to establish and determine what shall be the riparian rights which shall pertain to those who hold the title to lands bordering on the same. The case of St. Anthony Falls Water Power Company v. Board of Water Commissioners of St. Paul, decided November 29, 1897, by the Supreme Court (18 Sup. Ct., 157), was one which pertained to the rights of the plaintiff in that case as the owner of lands upon the borders or banks of the Mississippi River. This river was held to be a navigable stream, and all of the rights of the State of Minnesota grew out of that fact. In that case it was held that the riparian rights of the owner of land bounded by any navigable river depended upon the laws of the State where such land was located. In that case it was not held, nor was it held in any of the cases cited in the decision therein, that the rights of the owner of the land through which any innavigable stream flowed within the boundaries of any State depended upon the laws of such State, or that the said owner's right to such water depended upon such laws, as against one who claimed a right to the same under the laws of Congress. To so hold would uphold the view that a State might interfere with the primary disposal of the land of the Federal Government. When a party has obtained title to property from the National Government, the State government has no right to destroy that title, except under the power of eminent domain. The State of Montana can not step in and say, "The right to the water of Sage Creek, which the plaintiff acquired under the laws of Congress, you can not exercise in this State." This would be the taking of the plaintiff's property from him without due process of law. It is a recognized rule of law that a person who has appropriated water at a certain point in a stream is entitled to have so much of the waters of said stream as he appropriated flow down to him to the point of his diversion. The defendants, according to the allegations in the bill, are violating this rule, and should be enjoined.

The idea that there can arise any international water-right question in the case of the waters of an innavigable stream can not be maintained. The right to such waters, after the National Government has disposed of them, must always be a private question. For these reasons the demurrer in this case is overruled.

The correctness of the reasons upon which the decision is based in this case is denied by many lawyers in the West who have given much attention to water-right law. In the case (cited above) of Basey *v.* Gallagher (20 Wall., 671) Mr. Justice Field, of the United States Supreme Court, stated:

The act of Congress of 1866 recognizes the right of water by prior appropriation for agricultural and manufacturing purposes as well as for mining. * * * It is evident that Congress intended, although the language used is not happy, to recognize as valid the customary law with respect to the use of water, which had grown up among the occupants of the public land under the peculiar necessities of their condition.

The constitution of the State of Wyoming, Article No. VIII, section 1, declares: "The water of all natural streams, springs, lakes, or other collections of still water, within the boundaries of the State, are hereby declared to be the property of the State," and the act of Congress, approved July 10, 1890, admitting the Territory of Wyoming to statehood, accepted, ratified, and confirmed this constitution as being "republican in form and is in conformity with the Constitution of the United States."

The complete recognition of the principles which Judges Knowles lays down as the reasons for his decision in this case would mean the total disorganization of existing systems in the irrigated States, the overturning of constitutional rights, and the reversal of the decisions of the courts which have held generally that Congress, by the act of 1866, has surrendered sovereign proprietorship in the waters of natural streams.

NEED OF CLOSER APPROACH TO UNIFORMITY IN STATE LAWS.

That an undesirable, deplorable, and even dangerous state of affairs, in reference to water rights along interstate streams, exists in the irrigated regions of the West by reason of diverse, nonuniform, and incomplete irrigation legislation is evident. That this state of affairs if not improved will become, by reason of the rapidly enlarging number of individuals and the increasing value of interests affected, more undesirable, more deplorable, and more dangerous, is absolutely certain. It is also certain that a continuation of present conditions will retard the growth of irrigation interests, render property the value of which depends upon irrigation less valuable by reason of the uncertain tenure and instability of water rights, and will be generally detrimental to the welfare of the people of the West, vitally interested as they are in proper and equitable irrigation laws.

Thinking men, devoted to the work of securing for the West permanent welfare and prosperity, seek a remedy which shall improve the present unsatisfactory conditions in this great factor of Western development. Whether a practical remedy can be found and made effective so as to secure desired results is a question hard of solution. In the establishment of law and rules of society individual natural rights are relinquished voluntarily in order that a measure of uniformity may be reached by which all may be benefited and protected, and all legislation under forms of self-government carries with it the idea of sacrifice upon the part of the governed in order to make such legislation effective. To establish uniform irrigation laws which shall apply to the entire arid West, the rights of many individuals which have been secured by reason of too liberal provisions of the laws of the State in which they happen to reside, or by the absence of all irrigation laws, or through other causes, would doubtless be encroached upon by the formation of a general system which might demand concessions from one State to meet the requirements of an adjoining one. In fact there might and doubtless would be entire communities called upon to make sacrifices in order to establish a general law or system for the good of all. But the number of persons who might suffer at this time, or at some time in the immediate future, by reason of changes which might be necessary in the laws of the State in which they live, is infinitely small compared with the number who suffer from the imperfections of the present system, or with the number who would have to make concessions from *acquired rights* should action in this direction be deferred for any con-

siderable time. Consequently the earlier an earnest effort is made to effect a radical change in the direction of reform and toward the establishment of a general system of water-rights law in the irrigated regions of the country the less opposition is likely to be encountered from individuals, communities, or States; and the earlier action is taken the less the friction will be from the ensuing changes.

NATIONAL LEGISLATION.

An adequate remedy through national legislation, it is to be feared, is out of the question. The General Government, by act of Congress of July 26, 1866, formally withdrew from interference with local customs, laws and decisions of courts relative to the use of the waters of nonnavigable streams. The Territories admitted to statehood subsequent to that act have embodied its general provisions in their constitutions, which have been approved by Congress by the terms of the various acts of admission. Any general legislation by the National Congress relative to water rights would mean an upheaval too great and too far-reaching to be practical. It would mean that a number of the States would have to make changes, not only in their laws, but in their constitutions, and would overturn the long line of established practice and decisions of the courts in dealing with this question.

The waters of natural streams within the boundaries of the several States in the irrigated regions being, by virtue of constitutional provision, by the abandonment of control by the General Government, or by usage or the decisions of courts, the sole property and under exclusive control of these States, it is clear that reform of evils which exist by reason of defective legislation in these States, or by reason of lack of all legislation, can only be effected by proper legislation on the part of the legislative branch of the governments of these States. It is clear, too, that reform can not be effected unless the several States, in forming new legislation or correcting that which already exists, take into consideration the rights of the citizens of neighboring States as well as the rights of their own people. No uniformity can be secured if legislation continues in the future, as in the past, to be enacted for the benefit of individuals or local communities and not of such general nature as to make it applicable to the great body of irrigators of the entire area of irrigated lands.

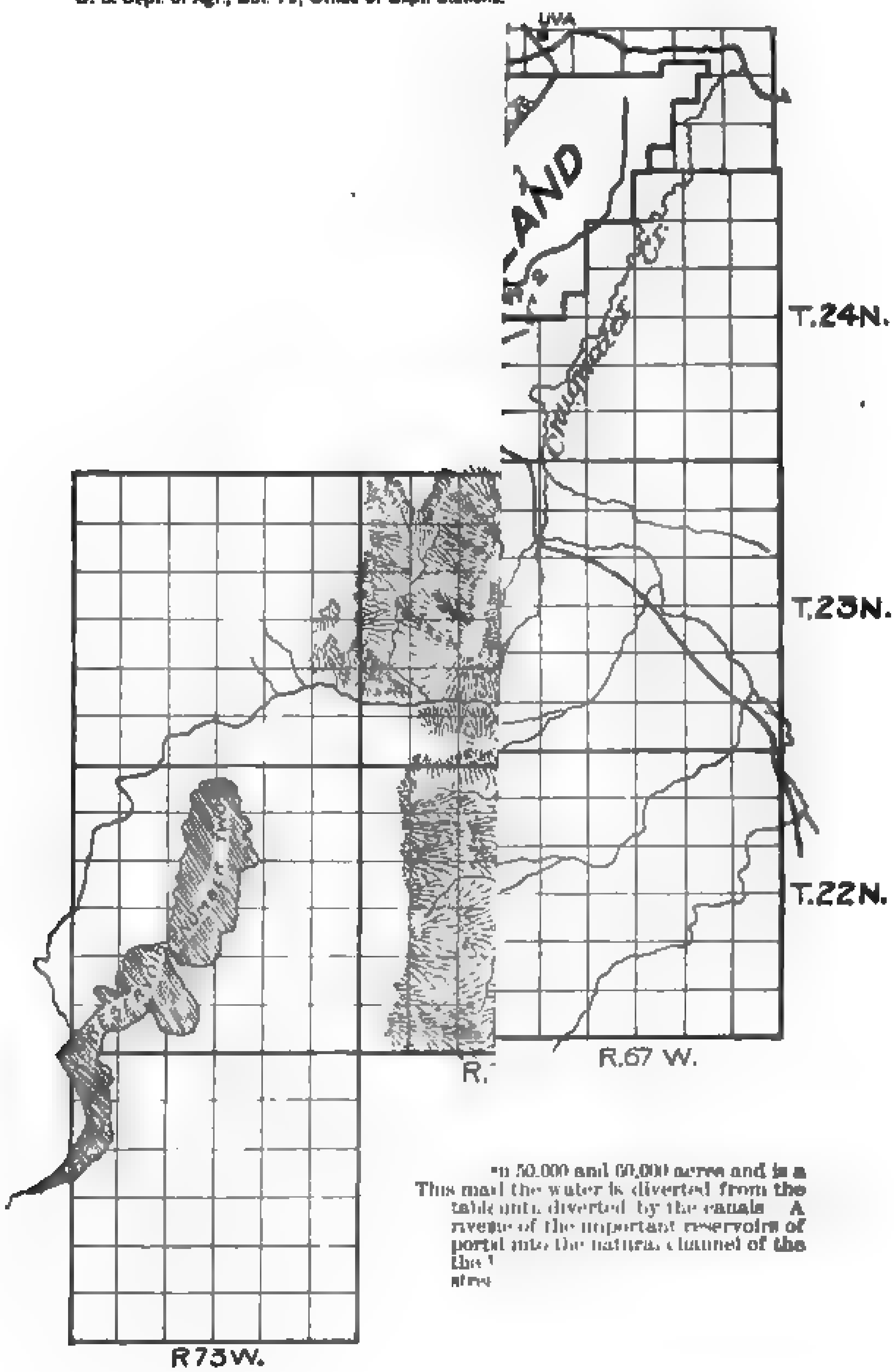
Reform in this matter can not well be accomplished by arbitrary action upon the part of State governments, but must be accompanied by an educational movement which will convince irrigators that proposed legislative changes are practicable and desirable.

CONVENTION TO CONSIDER UNIFORM LAWS.

As reform must in the main come from the voluntary action of the States, and as it is, without much question, the general desire of the residents of the irrigated regions of the West that some such plan of

voluntary legislative procedure be tried in order that reform in this important matter may be secured, a plan is suggested, which, if adopted, may be the means of consummating uniformity of legislation upon water-right questions in the West. It is that the governor of each State and Territory in the irrigated region appoint two commissioners, one to be the State or Territorial engineer, or the officer whose position most closely conforms to that of State engineer, and one practical irrigator, engaged in irrigation. The commissioners to meet at some convenient place within six months from the time of their appointment and formulate a system of irrigation laws for each State and Territory so represented, conforming as closely as may be possible to a general code, varying from this to meet local conditions where necessary; the system adopted for each State to embody general and uniform methods of recording, a general standard of measurement of water rights, and general provisions providing for adjudication of the waters of interstate streams; and the system so adopted to be submitted to the legislatures of the various States and Territories at their next succeeding session, and recommended for adoption.

While the adoption of this plan might not be followed by immediate and complete reform in the matter of water rights legislation, it might possibly be the stepping-stone to such reform. Annual congresses, such as the trans-Mississippi, the irrigation, and similar meetings, are held for the purpose of influencing national legislation upon matters of general interest to the West. It seems reasonable to suppose that the recommendations of a convention composed of practical irrigators and irrigation experts, upon a question of immediate and vital importance to every State and Territory within the irrigation district, would carry great weight with the lawmaking bodies of these States and Territories. It is possible that but few of the States would adopt the recommendations of such a convention, but a great advance will have been made in the direction of uniformity when any two contiguous States work upon similar lines, employ uniform methods, and provide for joint adjudication and apportionment of the waters of a stream common to both States.



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U. S. DEPARTMENT OF AGRICULTURE,

OFFICE OF EXPERIMENT STATIONS,

A. C. TRUE, Director.

IRRIGATION

IN THE

ROCKY MOUNTAIN STATES.

BY

J. C. ULRICH.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1899.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., November 22, 1899.

SIR: I have the honor to transmit herewith a paper by J. C. Ulrich on irrigation in the Rocky Mountain States and to recommend its publication as Bulletin No. 73 of this Office.

Settlers from the East, familiar only with agriculture under humid conditions, frequently make costly mistakes when they attempt to farm under the widely different conditions which prevail in arid regions—mistakes in locating claims, securing water rights, and in using the water. This bulletin is intended to explain the agricultural conditions prevailing and the methods of acquiring and using water for irrigation practiced in that portion of the arid region covered more particularly by the States of Colorado, Wyoming, Utah, Idaho, and Montana, in which the conditions and methods are somewhat similar, the main purpose being to instruct those to whom the subject is new and strange. For this reason, the subject is treated in an elementary manner.

Respectfully,

A. C. TRUE,
Director.

Hon. JAMES WILSON,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
IRRIGATION INVESTIGATIONS,
Cheyenne, Wyo., June 15, 1899.

SIR: I have the honor to submit for publication a paper entitled "Irrigation in the Rocky Mountain States," by J. C. Ulrich, C. E., who has had a long and varied experience in building and operating irrigation works.

The marvelous growth of the western half of the United States is more largely due to irrigation than to any other single agency. This has been almost wholly the work of men who at the outset knew nothing of either the methods of watering crops employed in other irrigated lands, or of the laws and customs by which rights to rivers are acquired and enforced.

At first there was little need of such knowledge. The beginnings in each State were simple. It required less skill and experience to plow the furrow and water the Mormon field from City Creek in Utah than it does for an Iowa farmer to drain the water off his land. The first ditches were little more than plow furrows. Many were built without surveys or records of rights. Diverting water raised no question of priority or interference with vested rights. The problems of the first settlers in each arid State were far easier of solution than those which beset the farmer under irrigation to-day, no matter whether he is a newcomer or has the experience of years behind him. The first settler on a stream thought of nothing except to find a place where he could get public land and secure a bend in the stream where the banks were low and the fall rapid. To-day he is beset by complications growing out of streams already having more ditches than their water supply will serve, by claims to more water than the ditches will carry, by complications growing out of the divided authority over land and water, and by legal and engineering questions whose solution in all irrigated lands has taxed the wisdom and patience of the ablest minds.

Success to the early irrigator involved only the right use of the plow and shovel. When there was only one ditch from a river the priority of its right did not need to be looked after, but when there are fifty the number of the priority and the laws for its protection determine not only the value of the *ditch* but of all the land it waters.

A break in the individual ditch of the pioneer could be repaired at the expense of a few hours' labor, and without injury to the crop it watered; but in the great aqueducts which have succeeded them, which require massive head gates to withstand the floods which beat against them, and which stretch away for scores of miles from the source of supply, a single break may mean the expenditure of thousands of dollars in repairs, the loss of the year's work to many farmers, and widespread disaster to the community. Under the pioneer ditches success in irrigation was as much a matter of individual effort as it is under rainfall, but under many of the large canals now in existence the returns of the farmer depend on many things besides his own labor. There must be wise and effective division of the stream, while the watchfulness, honesty, and skill of the inspector or "ditch rider" are as important as a fertile soil. A just water-right contract can make a contented community, while an unfair or unwise one is an effective promoter of discord.

The material development of irrigation has outrun its organization. To bring the conflicting interests which have already been created into harmony is a perplexing problem to those who have given years of study to the question. It is not difficult to understand how confusing it must be to the newcomer who learns of these complications for the first time. Every irrigator of experience knows that the title to the water is more important than the deed to the land it fertilizes, but the beginner, unfortunately, often learns this after it is too late for the knowledge to be of any benefit.

It is to the irrigated land that the home seeker must look hereafter in his effort to secure industrial independence. The vacant lands and unused rivers of the West offer the greatest inducements to those who have energy and self-reliance and but little else out of which to create a home. But the dangers and problems which confront them are greater than those which beset the settlers of a quarter of a century ago, and they ought to be enabled to learn what these dangers are in some less costly school than that of experience.

Respectfully,

ELWOOD MEAD,
Irrigation Expert in Charge.

MR. A. C. TRUE,
Director.

CONTENTS.

[redacted]

ILLUSTRATIONS.

IRRIGATION IN THE ROCKY MOUNTAIN STATES.

INTRODUCTION.

The differences between agriculture under irrigation and that in regions of abundant rainfall are as marked as those between the appearance of a landscape in Arizona and one in Illinois. The home seeker from a humid region finds that his past experience as a farmer is of little service in choosing a location upon the arid lands of the West. The soil and climate are different and the conditions which farmers discuss are strange. As a result he usually follows the advice of those who settled before him, and the final result of his efforts depends in large measure on the kind of company he falls in with at the outset.

If he is a practical farmer he has been accustomed to consider the fertility of the soil, its drainage, the proximity to market, and the social advantages of a community the leading factors in making a location desirable; but when he casts his lot in an irrigated district he finds that all the unirrigated land looks alike and all apparently worthless. He frequently finds that lands conveniently located, close to market, and with a contour and slope suited to irrigation, are yet unoccupied and for sale at small price. If he seeks for the cause from a disinterested source he will probably learn that it is lack of a water right—that other lands absorbed the stream before ditches to water the land in question were built, and that when streams run low no water is left for its use. If he is not so informed at the outset, he may learn of this through unhappy experience.

The significance of a water right, and the importance of having both an adequate supply and adequate provision for its just distribution, are matters which the home seeker is most apt to overlook, as they were the last things to be properly appreciated by the early settlers.

Nor are the beginners the only ones who make mistakes in locations or feel themselves perplexed by the problems growing out of the distribution of the water of rivers among those dependent thereon. Old and capable irrigators find it hard to discriminate between the merits of widely differing ditch contracts for the supplying of water or to understand what rights farmers have in streams under the conflicting court decisions growing out of the litigation over water rights. They are learning that farming under irrigation requires a study of other things besides

the application of water, and are to-day studying the broader questions with an earnestness and alertness which must in time result in important changes in present laws.

Two causes explain the rapid extension of irrigation in the arid West. One is the inability to raise crops without it; the other is the ease and cheapness with which the first ditches were built. To the New England hill farmers the distribution of a layer of water over every inch of a wheat field seems a labor of great magnitude and difficulty; but when one has seen the gently sloping table-lands of Colorado, Kansas, and Nebraska he realizes that spreading water over the surface is as simple as plowing corn in Iowa. The dweller along the sluggish, deeply sunken rivers of the middle West marvels at the methods by which the irrigator gets his water supply above the surface; but when he looks at the mountain torrents, which have scarcely any banks and have a fall so great that the ditches which leave them seem to be running up hill, this mystery is also explained.

The first steps in practical irrigation are surprisingly simple, easily understood, and as easily carried out. Many ditches have been built by men who knew nothing of either irrigation or engineering. A few days' instruction and experience will make any man of ordinary intelligence able to irrigate most farm crops without any further direction or oversight. This does not mean that he knows all there is to be learned, or that further time will not enable him to do his work with greater ease or with increased economy in the use of water. The requirements of different crops and the time when water should be applied vary greatly, and the experienced irrigator has a great advantage over the novice; but this does not prevent beginners, without either experience or direction, raising good crops the first year. On land reclaimed, and with an ample water supply, success with beginners is the rule rather than the exception.

The primary purpose of this bulletin is to describe agricultural conditions in the Rocky Mountain region, to give the methods by which the waters of streams are appropriated, diverted, and used, and to point out some of the difficulties which may confront those to whom the whole subject is new and strange. The discussion is confined to that territory in which conditions are somewhat similar. The great diversity in conditions and methods in different parts of the arid region makes such a limitation necessary. The territory considered in this bulletin embraces particularly the States of Colorado, Wyoming, Utah, Idaho, and Montana, and includes the country which slopes east and west from the summit of the Rocky Mountains. In these States the waters of streams are under more or less strict public control and there is also a practical uniformity in irrigation methods, while the general character of the water supply, climate, and soil is not so very dissimilar. This territory also includes all of the States which have by constitution and statute abrogated the common-law doctrine of riparian rights.

GENERAL CHARACTERISTICS OF THE ROCKY MOUNTAIN STATES.

The region under consideration embraces about one-sixth of the total area of the United States. The different portions of this vast extent of country present every conceivable feature of variety and contrast. There is, however, one characteristic common to all localities within its limits, which establishes a condition which necessitates a radical departure from the practices under which agriculture is conducted in the more densely populated humid region, which definitely affects the customs of its people, raises new issues of national importance, places its indelible stamp on the very face of the landscape, and fixes a definite limit to the population which this region will support. This characteristic is that aridity of climate which makes the artificial application of water necessary to successful agriculture. This climatic condition necessitates methods of procedure in the conduct of farming operations which are unknown to the eastern farmer.

CLIMATE.

It would be useless to attempt a detailed description of the climate of this region, both because of the enormous extent of territory involved and the almost limitless variety due to local topographic conditions. Extending from Canada on the north to New Mexico on the south, it has a wide range of climatic variation due to latitude alone. There is found, also, the widest diversity in climate and temperature at points in close proximity, due to their great difference in elevation. An unusual percentage of bright, sunny days, an invigorating, bracing atmosphere, and that aridity from which the region gets its name are characteristics, however, which are common to all parts of the arid region and prevail to a greater or less degree in all latitudes and at all elevations.

The precipitation, like the temperature, is characterized by marked differences between points in close proximity. It is usually much greater upon the mountains than in the valleys, and generally increases with the altitude. At all points where the elevation is not such as to prohibit successful farming operations it is less than that characterizing the humid regions east of the one hundredth meridian of longitude, and is generally insufficient to guarantee successful results in agriculture without the aid of irrigation. In parts of southern Utah it does not average more than 6 inches per annum. In the farming regions of Idaho and Colorado it is from 12 to 15. It may be stated, generally, that it varies in different parts of the territory under consideration between the extremes of 6 and 24 inches per annum, except in a few restricted localities where the proximity of high mountains causes a rainfall sufficient for agricultural operations.

We thus see that the line of demarcation between the strictly arid and the strictly humid sections is not a clearly defined one. In some

localities within the arid region, particularly in western Kansas and Nebraska, in the valley of the Great Salt Lake, and in parts of southeastern Idaho, considerable "dry farming" is carried on. The results, however, with few exceptions, are not satisfactory. In years during which the precipitation is above the average, and its distribution with reference to the farming season is fortunate, bountiful crops are sometimes matured, but no reliance can be placed upon a continuance of those conditions. One or two seasons of good crops may be and generally are followed by a series of years of partial or complete failure. The farmers in such localities are never continuously prosperous. It requires all the proceeds of a series of good crops to carry them through the succeeding years of drought. It is therefore a serious mistake for people to settle in such localities with the intention of farming without irrigation.

Along the eastern border of the arid region is a strip of country, embracing portions of Kansas, Nebraska, the Dakotas, and a part of northwestern Texas, which is sometimes designated as the "rain belt." It derives its name from a theory that there is a progressive movement of the boundary of the humid region westward. This theory is based upon the assumption that the extension of railroad tracks and telegraph wires into the arid region is effecting a change in climatic conditions resulting in an increased rainfall, and that the settlement of the country, with its subsequent cultivation of the soil, assists in bringing about this result. That thorough cultivation materially modifies the effects of a given degree of aridity is not open to reasonable doubt, but that any perceptible change in the climate is brought about by the agencies mentioned, is a proposition that to the writer does not appear worthy of serious discussion.

There are, however, annually a considerable number of settlers who locate in such localities and practically test the rain-belt theory, and the periodical exodus of a like number who have thus wasted several years of time and labor attests the completeness of the demonstration so far as these are concerned. Under an efficient system of irrigation, however, the problem assumes a different aspect. The soil of the rain-belt country, like that in other parts of the arid region, is fertile and productive when water is applied in sufficient quantities. Without this adjunct it will not produce satisfactory crops, and its value must be limited by its availability as a stock range, for which purpose it is in many places well adapted.

APPEARANCE AND INDUSTRIES OF THE REGION.

To the visitor from the East the appearance of the arid region and the conditions under which farming is carried on are sources of constant surprise. He notes the absence of continuous stretches of cultivated fields and human habitations and is impressed with the vast *extent of* barren plains between the comparatively small productive

areas. Often the cultivated land is confined to a narrow strip of green along some small water course; sometimes it is of greater extent, reaching for a considerable distance back from some large river; but it is always bounded by the line of the irrigation canal, and is always of small extent compared with the barren areas beyond. The extent and number of the irrigated tracts are constantly increasing, but the available water supply and the topographic and climatic features of the country unite in limiting their extension, and they will always remain but a small fraction of the total area of this region.

Within this domain three great industries principally engage the attention of the people, viz, mining, agriculture, and stock raising. Of these, mining was until recently the most prominent and important, but at present the value of the products of agriculture largely exceeds that which results from mining. The principal mineral products are gold, silver, lead, iron, copper, and coal. The agricultural products include nearly everything which can be produced within the limits of the United States, the great variety and diversity in soil, climate, and elevation presenting the conditions necessary for the development of every form of farm product known to the latitudes embraced within its limits. By making possible a cheap food supply in this region, agriculture by irrigation has rendered mining more profitable, while the markets created by the latter industry have certainly been of the very greatest benefit and importance to the former.

Agriculture and stock raising are of course closely related, and in many localities largely dependent upon each other for success. The practice of running large herds on the range without adequate provision for their winter feeding is rapidly passing away throughout this entire region, resulting in the gradual establishment of the cattle industry upon a firmer and more permanent basis, and in the promotion and encouragement of actual settlement and cultivation of the soil. There will always be a very great preponderance of grazing lands over those which can be reclaimed by irrigation, and this fact gives the stock grower of this region a decided advantage over his eastern competitor; and the consequent demand for forage and grain furnishes in many localities a profitable market for the products of the irrigated farm, while the full utilization of the vast range will demand in many sections a large extension of the irrigated area and product. The combination of these two industries of farming and stock raising seems to be the ideal arrangement, and very many localities in the arid region offer exceptional advantages for such combination.

In the more mountainous localities agriculture does not assume a very prominent position, because large areas of land suitable for farming are not to be found, and it is only in the small valleys immediately adjacent to the streams that agriculture is attempted or can be followed with profit. Even these valleys can not all be successfully farmed on account of their great elevation, since farming, as a rule, can not be

conducted with success at altitudes exceeding 7,000 or 8,000 feet above sea level, and even at those elevations only the very hardiest products can be grown. These small valleys in the mountains, when favorably located at elevations ranging from 4,000 to 6,000 feet, present in many respects the most favorable conditions for successful agriculture under irrigation. The climate is often superior to that of localities remote from the mountains. They thus furnish more desirable locations for homes, and where the elevations do not exceed 4,000 or 5,000 feet they are often found to be superior to other localities for the production of deciduous fruits, which, under the favorable conditions of soil and climate here presented, respond with a bountiful yield, and the quality of the product is unsurpassed by that of any other part of the United States. These mountain valleys are also often contiguous to the public grazing lands, and thus afford especially good locations for stock raising. Generally speaking, however, the bulk of the irrigated area is on the extensive plains, the best land and facilities for marketing the produce being generally found in such localities.

CONDITIONS FAVORABLE AND UNFAVORABLE TO IRRIGATION.

Irrigation, in the region dealt with in this bulletin, is almost wholly a matter of gravity. The stream is tapped at a point where its channel is higher than the field to be watered. Thence the water is carried down hill in the ditch to the highest point to be covered. In spreading it over the field the laterals run on the ridges, and the shovel of the irrigator manipulates its distribution along or across the slopes below. When it has thus been brought to a level with the most elevated points upon the tract to be irrigated, it can be made to flow out over the land by the force of gravity alone, without any assistance from the irrigator beyond such manipulation as may be required to effect its uniform distribution over the minor irregularities of surface, which are eliminated as far as possible by careful leveling and preparation of the ground before irrigation is attempted.

Sometimes the water supply lies at a lower level than the land to be irrigated, and has to be raised. This occurs where the water supply comes from wells or other subterranean sources. In such cases it is raised to the required elevation by pumping, or by any other method which is found most convenient and economical. Pumping water for irrigation, because of the large volume required, is attended with great expense and can not usually be employed with profit except for the reclamation of land devoted to the cultivation of crops which represent great value per unit of area devoted to their production. In the cultivation of oranges, lemons, and other fruits which yield a product whose value is several hundred dollars per acre, and where the amount of water required is relatively small, pumping may be resorted to with profit; but in the growing of cereals and the ordinary farm products of the temperate regions, the cost of the pumping plant and its operation is often prohibitory.

FIG. 1.—HEAD GATE OF RIDENBAUGH CANAL, BOISE RIVER, IDAHO.

FIG. 2.—HEAD GATE OF JORDAN AND SALT LAKE CITY CANAL, UTAH.

FIG. 1. AMITY CANAL, ARKANSAS VALLEY, COLORADO.

FIG. 2. CANAL NEAR BILLINGS, MONT.

In most cases, however (in all where irrigation is conducted upon an extensive scale), the water supply is obtained from running streams, which in the arid region generally have very high gradients, thus rendering their diversion upon the adjoining lands comparatively easy. Where the land to be irrigated lies along the immediate border of the stream and is but little elevated above the latter a dam may be constructed which will serve to elevate the water to the required level. This is a practice very frequently adopted in irrigating low bottoms, but is applicable only where the land is but slightly elevated above the stream; as where its elevation is very considerable the height of dam thus required would, in most cases, involve an expense prohibiting its building.

Frequently the lands to be reclaimed occupy positions remote from the stream whose waters are to accomplish their irrigation, and are elevated several hundred feet above it. In such cases neither pumping nor damming the stream would be feasible, on account of the expense involved. If the stream had but a slight fall, land so situated could not be irrigated from it at all. One of the characteristics of the streams of the arid region, however, as noted above, is the excessive declivity of their slopes. There are few whose fall is less than 4 or 5 feet per mile, and 40 feet is not unusual, especially in the case of the smaller streams in the vicinity of the mountains. When, therefore, it is desired to irrigate a body of land which occupies a position of great elevation above the stream selected as its source of supply, the elevation of the latter does not necessarily prohibit the enterprise, because, while at all contiguous points along the stream the water is much below the land, the excessive fall characteristic of these water courses permits of the selection of some point further upstream, whose elevation exceeds that of the land whose irrigation is desired, and from this point its waters may be conducted by means of a gravity canal to the lands to be reclaimed. This point of diversion may be, and frequently is, many miles up the river from the lands to be watered. (See Pls. II and III.)

The lands irrigated usually lie between the ditch or canal and the stream furnishing the supply, and below the former. The water is drawn off by letting it out of the artificial conduit and permitting it to run over the lands below.

It is evident, however, that under some conditions irrigation can not be thus accomplished. If, for example, the irrigation of a body of elevated lands were contemplated from a stream whose rate of fall does not exceed that required by the canal through which the waters are to be conveyed to the land, the latter could not be covered. It would also be impracticable to irrigate an elevated body of land from a stream whose fall exceeded but slightly that required for the canal through which the water is to be conveyed to the land. If a canal whose slope must be 6 inches per mile is designed for the irrigation of land lying 150 feet above a stream whose slope is 1 foot per mile, its point of diversion would have to be located 300 miles up the stream from the lands

to be irrigated, and the enterprise would consequently be impracticable. For these reasons much of the land in the humid region could not be irrigated by gravity canals, even if the necessity existed, since the streams, while affording an abundant supply, have generally such low gradients that the diversion of their waters through gravity canals could not be successfully accomplished.

HOW CANALS AND DITCHES HAVE BEEN BUILT.

It is not so very long since the settlement of the arid portion of the United States, and especially the carrying on of agricultural operations within its limits, was pretty generally regarded as impracticable if not impossible. Its actual development is already far beyond the dreams of half a century ago, and we do not yet realize its ultimate possibilities. As a consequence the importance of irrigation and the various problems connected therewith have not been generally realized or understood. In the older irrigated countries the construction and operation of canals, as well as the distribution of water, is under the most strict government supervision and control, if not ownership. The wisdom of the system of operation measures in a large degree the prosperity of the people who live under it. Our system is yet in a primitive condition. The development thus far reached has not been under any comprehensive public policy, but is rather a natural outgrowth of conditions.

THE SMALL DITCH OF THE PIONEER IRRIGATOR.

During the earlier period of the settlement of the arid region, before the possibilities of irrigation had come to be generally recognized, and prior to the advent of a population sufficient to warrant definite efforts toward organization in the development of its resources, irrigation was limited to the individual enterprise of pioneer settlers who formed the advance guard of civilization upon the frontier. These pioneers, having selected suitable locations for farming and ranching operations, constructed each his own ditch for the irrigation of his individual lands, and operated it independently in the manner best suited to his interests.

The individual ditch appeals to the inherited prejudices and habits which the settler brings with him. Even if it costs more, he often prefers it to the enforced submission to regulations which dependence on partnership ditches or canals involves; hence on each stream the locations for such ditches are early sought out. When those in the main valley are gone, locators look higher up in the mountain valleys and along the rivulets which go to make up the main stream. These opportunities still exist in some parts of the country, but they are rare and hard to find. The pioneer makes use of all such opportunities, and they are now to be found only along water courses remote from the centers of population, where all the drawbacks of the frontier must

be encountered. The gain in first cost is thus counterbalanced by the attendant disadvantages of location. The building of individual ditches is, therefore, largely a thing of the past.

EVOLUTION OF THE COMMUNITY DITCH.

The evolution of irrigation on the majority of streams has followed the same successive steps. Frequently the ditch of the pioneer was so located as to be conveniently and economically enlarged and extended to cover the lands of subsequent settlers. In such cases arrangements were often made with the original owner by which such enlargements and extensions were made and the later settlers became part owners in the ditch, which has often been enlarged and extended many times and thus grown from the small ditch constructed and owned by the first settler to a large partnership or community canal, in which each owner of lands irrigated by it has purchased or worked out an interest, and contributes to its annual maintenance in proportion to the amount of water used by him.

After the available lower lands near the stream have been taken up and rendered irrigable by the individual or partnership ditches, larger and longer canals are often projected to cover the mesas and benches above. These also are often built, owned, and operated by the owners of the lands to be reclaimed by them, the principal outlay being their own labor. These partnership or community canals have generally proven successful and satisfactory, and have been a most important factor in the development of the agricultural resources of the arid region. Their construction and operation are usually simple, and their value represents wealth created by the people who live under them. The operation and maintenance of such canals is generally satisfactorily accomplished through mutual agreement, by proportionate assessments of labor or money upon the various owners. The annual expense of operation is generally very small, and the value of land under such canals (which usually includes a proportionate ownership in the canal itself) is usually greater than that of similarly situated land under corporation canals. In many respects, where it is applicable, this individual or partnership system of canal ownership is an ideal one.

Although partnership and community canals, especially those which have grown up by the enlargement and extension of smaller individual ditches, are usually unincorporated mutual associations as above described, yet it often happens that a closer and stronger organization than one dependent upon mutual agreement is desired by the irrigators, and the result is the formation of the community irrigation stock company. In such a corporation the stockholders, as a general rule, are the farmers who expect to use the water thus made available. It generally originates and is organized in the following manner:

A body of lands suitable for farming purposes, and so situated with reference to a river or other satisfactory source of supply that it can be

irrigated with a reasonable degree of economy, is located and acquired by different individuals. If Government land, it is secured through the regular homestead or desert-land filings. If belonging to the State or a railroad company, it is acquired through purchase. Sometimes both State and Government lands are available, of which the alternate sections belong to each, respectively. In the case of Government lands, many of the filings may have been made long before the irrigation proposition in question had assumed definite form, the same having been made upon the assumption that irrigation was possible and would sooner or later become an accomplished fact.

For the purpose of specifically illustrating the method of organizing and conducting the affairs of such a community irrigation enterprise, it will be assumed that a number of individuals have made filings upon different tracts of Government land, comprising in the aggregate an area of 8,000 acres, or that they have acquired the same area through purchase from the State or from a railroad company. This land is, of course, arid and unproductive without water, and before its irrigation can be effected a canal or other conduit must be constructed for conveying thereto the waters of some adjacent stream. A meeting of the owners or claimants is therefore held, and the necessary plant is agreed upon; the amount of water required, the size of canal needed, and the approximate cost of the undertaking are determined; and a board of directors is elected, who appoint the executive officers for conducting the affairs of the company. It will be assumed that the probable cost of the works has been determined to be $50,000. The capital stock is then fixed at this amount, and is divided into 500 shares at a par value of $100 each. It will be assumed that the canal is to carry 100 cubic feet of water per second of time. Under this assumption each cubic foot of proposed capacity is represented by a capitalization of $500, and, as there are 500 shares, each of the latter would represent one-fifth of a cubic foot of water. If 1 cubic foot be considered as the amount required for 80 acres of land, each of those who desires to irrigate this area should subscribe for five shares of stock, and for larger areas in the same proportion. There would, however, be no condition specifying the number of shares which any purchaser must acquire, though it would be advisable that each landholder purchase the number necessary to accomplish the satisfactory irrigation of the area proposed to be cultivated, since the number of shares held will determine the amount of water which he will receive. Each landowner or other person desiring water shares now enters his name upon the subscription or stock book of the association, and the secretary enters opposite thereto the number of shares for which he has subscribed, opening at the same time an account with the subscriber, upon which he is charged with the value of the stock contracted for, and given credit, under the proper dates, for any payments made thereon.

While it is generally a fact that a majority of the holders of stock in

these concerns are actual farmers who propose to live upon and themselves farm the land to which the water thus acquired is to be applied, this is not a necessary requirement, and frequently a number subscribe for stock who do not own any land, but acquire the water either with the intention of selling it to others or because they intend subsequently to acquire land to which it may be applied. There are others, still, who, while owning land capable of irrigation from the proposed system, do not subscribe, because they do not intend to farm the land, but expect to sell it at an advanced figure, after the works are in operation, to those who already own or may subsequently acquire stock, either from the company direct or from other stockholders who may, for any reason, desire to reduce their holdings.

Each subscriber now becomes nominally a stockholder, though certificates of stock may never be issued, and he may proceed to work in the construction of the plant at a price for labor which has been fixed and scheduled by the board of directors, which, through the president of the association, has appointed a foreman and timekeeper to supervise the details of the work and keep the time of the operators engaged thereon. At the end of each month the foreman or timekeeper turns in to the secretary a statement setting forth the amount and value of the work contributed by each subscriber, and these amounts are by the secretary credited upon the accounts of the several stockholders in partial liquidation of their indebtedness to the association, incurred through the purchase of stock.

When the construction of the plant has been completed, the various accounts are made out and certificates of paid-up stock are issued to those who are found to have worked out the full amount due therefor. Those who are found not to have contributed the amount of work necessary to liquidate their indebtedness are given credits representing the amounts paid, and their accounts remain charged with the balance yet due, the adjustment of which may be required in the form of a cash payment, or may be permitted to stand on the books until an opportunity arises for working it out at a future date. Where stockholders at the completion of the construction have contributed work in excess of their stock subscriptions, the amount thus overpaid may be refunded in cash or allowed to stand as a credit upon the books of the association and subsequently applied in liquidation of assessment liabilities arising through expenditures incident to operation and maintenance of the plant.

If it should be found, upon the completion of the works, that the expense of construction was less than the amount realized through the sale of stock, the difference may be distributed to the stockholders in the form of a dividend, to each in proportion to the amount of his stock, or it may be permitted to remain in the treasury and applied to the liquidation of subsequent indebtedness incurred in operation and maintenance. It more frequently occurs, however, that the actual cost

of the works exceeds the estimate upon which the capitalization was based, and that additional funds are required to complete the enterprise. These may be realized by the levy of a pro-rata assessment upon the outstanding stock, or through the issue and sale of additional stock to the amount required. The general method of organization and procedure is similar in the case of unincorporated community associations.

When the works have been completed and actual operations inaugurated, certain expenses incident thereto are encountered. These consist, in the main, of salaries and expenses of officers, wages of ditch riders or patrolmen, repairs necessary to structures, and other incidental expenditures that need not be enumerated in detail. These liabilities are usually provided for through pro-rata assessments against the stockholders.

As noted above, the essential features of this kind of stock irrigation company and of the unincorporated community canal are not dissimilar. The works of both are created, owned, and operated by local capital and labor, and their inception and organization are brought about by similar causes and carried out along similar lines. Both depend for their success largely upon local ownership, economical management, and the lack of necessity for any great cash outlay in their construction and operation. Communities with little capital except pluck and muscle have, under these methods, created canal systems that are among the best and most successful in the whole arid region, and which, from modest beginnings, have ultimately resulted in the growing up of thriving towns and populous and prosperous farming districts under them. This is the system of construction and management common in Utah under the operation of the district irrigation law formerly in effect in that State. The districts formed under this law are in effect voluntary mutual associations or companies for the purpose of construction and operation of canals, the cost of which is raised by assessments on the various owners in proportion to their respective interests in the works and quantity of water to be used by them.

The farmers in many localities are prejudiced against stock corporations and prefer to operate their canals under mutual agreement. In Wyoming, for example, it is doubtful if one in fifty of the community ditches are incorporated. As trouble sometimes arises in regard to collection of assessments, a law has been enacted in that State the object of which is to compel the payment of such assessments in case of unincorporated community canals. The same aversion to corporations in connection with irrigation is noticeable in greater or less degree in the other States.

Although opportunities for participation in the development of new enterprises under the community system still exist throughout many parts of the arid region, they are becoming more rare with the advance *of time.* This is particularly true with reference to those localities in

convenient proximity to the more important towns and cities, where lands and water rights under such organizations can now generally be acquired only through purchase.

THE CORPORATION CANAL.

Throughout all parts of the arid region there are found areas of superior land in the form of high plateaus or mesas, located sometimes at considerable distances from the more important streams, usually occupying positions of great elevation above the latter, and frequently separated therefrom by high rocky bluffs or ranges of hills and mountains. The exceptional fertility of many of these lands, together with their wonderful uniformity of surface, render them especially attractive to the irrigator. They are the best lands, but their location is frequently such that to secure the proper elevation dams have to be built to raise the water at the head, and the canal must wind its way for many miles through rocky canyons and along precipitous cliffs, and be carried across ravines and chasms in pipes or flumes, whose design and construction require the best engineering talent and experience. The expense thus incident to the construction of the works is frequently so great that neither the individual nor the community can successfully undertake its execution; hence they await the coming of corporate capital or State aid. The agency through which many of these comprehensive, difficult, and expensive works of irrigation have been accomplished is the institution known as the land and irrigation corporation, which has been the successor to the individual and community enterprises in the development of the agricultural resources of the arid West. The latter successfully held the field so long as the propositions open to consideration were simple, inexpensive, and readily available. In the development of these they proved to be admirably adapted to the requirements of the situation, but as the simpler problems were solved first, operations became more difficult and expensive with the increasing magnitude and complexity of the undertakings, and finally a point was reached where progress must cease unless the assistance of some more powerful factor could be enlisted which might successfully grapple with the greater issues presented.

It was at this juncture that the irrigation corporation came to the rescue, and it has since become a prime factor in the development of the agricultural resources of the arid region. The individual and community efforts, however, had paved the way toward the new departure, and the substantial results achieved by them made it possible for this powerful agency to become a factor in the work. It was their successful efforts that had first subdued the implacable desert and demonstrated the fertility of its lands and the possibility of creating prosperous agricultural homes and communities in a land which had long been regarded as a suitable dwelling place for only the buffalo, the coyote, and the Indian. These pioneers had demonstrated that the so-called

desert lands of the arid region, whose acquisition from the Government could be accomplished practically without cost, assumed a value under the practice of irrigation equal to that of the very choicest farming regions of the Eastern and Middle States, and the uniform success which crowned their efforts in this field attracted the attention of capitalists to these enterprises as presenting unusual opportunities for profitable investment.

Under the individual and community régimes the prime incentive was the transformation of certain desert lands into productive farms, which were to serve as the permanent homes of the individuals who inaugurated and executed this work of reclamation, and they expected their profits through the actual farming of the lands so reclaimed.

With the corporation, however, it was different. The opportunity thus presented for investment was with it the prime consideration. It was no part of its programme to actually improve and farm these lands; none of the individuals composing its personnel ever expected to make a home thereon. In most cases they were all nonresidents, whose homes were not even within the limits of the arid region. The object of their operations was the acquisition of large bodies of lands and valuable water franchises, which were to be sold at a profit, after the development of their proposed irrigation plant, to people who might desire to improve and actually farm the lands. The actual relation of the real owners of these enterprises to the properties themselves is usually even more remote than this. The financial interests are generally represented by the bondholders, who through the purchase of bonds have advanced the money for the building of works.

The stock of the corporation irrigation systems is not, as in the case of the community stock organization, in the hands of the farmers and actual water consumers under the system; it is held and controlled by the promoters and organizers of the enterprise. Its affairs are also controlled by a board of directors, who are elected by a vote of the stockholders. The executive officers are the president, secretary, and treasurer, but the details of the executive management usually devolve upon an officer appointed by the board, who is called the manager (sometimes the general manager), who lives, or should live, within easy access to the works. The manager has the appointing of and directs the operations of all the employees beneath him in rank, and is in fact the local dictator of the policy and management of the concern.

In most cases these corporations own and handle lands as well as water, the land feature being frequently the more important of the two. Where they own lands the latter are generally sold in connection with water, at a price which includes both. The land is rarely sold alone, since it has no value except in connection with the water, which usually can not be secured except from the irrigation company.

Under this corporation régime water is not represented by shares of stock, as it is in the community organizations hereinbefore described,

but by a "water right," which is a right to a certain specified quantity of water, or to the amount necessary to irrigate a certain tract of land, the amount given for this purpose varying with different companies. The quantity of water really necessary to irrigate an acre varies widely in different localities, and again materially with the crop under consideration. While in Colorado and Idaho a flow of 1 cubic foot per second is usually furnished and applied to 50 acres of alfalfa, the same volume will supply the necessities of 500 acres of citrus fruits in southern California.

The irrigation corporation constructs, operates, and maintains the main line of canal or other conduit by which the water is diverted from the river and conveyed to or within easy access to the land to be reclaimed; and in addition thereto, and particularly where these lands belong to the corporation, it usually constructs a number of large lateral branches, which are diverted from the main line at convenient points and traverse the principal bodies of lands. These are designed for the purpose of bringing the water within reasonable proximity to such lands as are located at considerable distances from the main works. The main canal or conduit necessarily occupies a position outside and above all the area to be reclaimed. Without these branches a decided hardship upon some of the water consumers would be involved in the necessary construction of private ditches of great length for conveying their water from the main works, a condition which would tend to place an embargo upon the sale of water. By means of this arrangement is also avoided the necessity, which would otherwise exist, for tapping the main line at a great number of points for the diversion of water for individual consumers, as well as the objectionable feature involved in the great multiplicity of private lateral ditches across the entire body of lands.

The main canal and these principal branches are operated, maintained, and controlled by the corporation, and are patrolled and regulated by ditch riders in its employ.

The settler or farmer who has purchased water rights from the corporation is generally permitted to divert the water from any point on the main canal or any of the laterals found to be most convenient, subject, however, to the approval of the general manager or local superintendent. In either case a head gate or regulating structure is placed at the point selected, for the purpose of regulating the amount diverted. This structure is the private property of the individual for whose use it is erected, though it is designed and placed in position by the company, and is controlled and regulated by the ditch rider, who keeps it locked at the required degree of opening and himself carries the key. The ditch conveying the water from this structure to the land to be irrigated is most frequently constructed, maintained, and operated by the owner of the land at his own expense. It is, however, not usually of very great length, and is comparatively simple and inexpensive. In some cases the company contracts to deliver the water at some conven-

ient point on the tract of land to be irrigated by it, in which cases all the lateral ditches are constructed and controlled by the company. This method involves a great additional expense of management and operation, and is not usually followed.

The practical results from operations conducted under the corporation régime do not materially differ, so far as the actual user of water is concerned, from those realized under the auspices of the community organization. The farmer's success is measured and determined almost entirely by the certainty and permanence of a satisfactory supply of water at a reasonable price. When these conditions are fulfilled it makes little difference under what character of organization he operates, the advantage of one system over the other being measured by the relative certainty of supply and the expense of getting it.

That the annual cost of water from a large corporation system is in most cases greater than from the smaller partnership or community canals is inevitable for several reasons. The latter are nearly always constructed first and occupy the best locations for cheap diversion and economical construction and do not usually require such extensive and costly headworks nor such a long line of expensive canal to be constructed and maintained before the irrigable area can be reached. These are advantages which the earlier enterprises have secured. In addition to more expensive construction and maintenance in the case of the larger canals, the salaries of general officers often materially increase the fixed charges, while the interest on the investment during the period between the construction of the canal and the settlement of the lands and consequent sale of water rights and the expense incident to securing such settlement are always very large items of expense which do not figure in the community systems. Many individual and community canals involve scarcely greater expense in construction and maintenance than do some of the individual and community lateral ditches which have to be constructed by the irrigators to convey their water from the company's main canal to their lands. So if the completed main canal systems should be turned over free to the landowners under them, they would have but similar advantages for irrigating their lands to those which many of the earlier settlers secured from the natural streams. To offset this added cost of irrigation which often prevails under these extensive corporate canals, the quality of the lands covered by them is often superior to that of the lands along the river bottom and adjacent which were settled upon and irrigated by the cheaper and more easily constructed ditches of the earlier settlers.

This plan of conducting the business of irrigation development has its good and its bad features. Through its agency great volumes of capital have been invested in the development of the agricultural possibilities of the arid region, much of which if dependent upon individual or community resources would have remained unproductive for many years. It is the corporation enterprises which enlist the interest

of a majority of intending immigrants. It is usually a part of their business to effect the sale and settlement of the lands under them, and their magnitude usually warrants the expenditure of large sums in advertising for this purpose. In some cases the results achieved under these systems not only prove satisfactory to the farmers, but prove them to be safe and profitable investments for capital. In many respects these large canals are the best and most economical systems for the distribution of water to the lands covered by them. These lands are usually in a large and compact body, which gives many social and industrial advantages to the settlers upon them. A greater area can be irrigated with a given volume of water than by means of a multiplicity of scattered individual and community ditches. Taken altogether, these large systems have many things to recommend them and have materially advanced irrigation development and benefited the landowners under them.

In most instances, however, the investors in these enterprises have not met with the success they deserve. Many causes have contributed to this result, some of which have already been indicated. The systems have almost uniformly cost much more than the first estimates, while the area of irrigable land under them, the irrigating capacity of the canals, and the rapidity with which their settlement and the consequent use of the water could be accomplished have all been almost as uniformly overestimated. Many years often elapse before the total discharge of the canal is utilized and before the income from water sold even meets the fixed charges for management and operation. Their location is sometimes distant from railway lines, cities, and local markets, which increases the expense and difficulties of securing settlers. If they follow individual and community ditches near settlements and markets already established they have later water rights than the earlier and smaller ditches. This inferiority of priority lessens the value of the property and is often a source of annoyance and expensive litigation with the earlier ditch owners and with their own consumers, who may have their water supply reduced or cut off in time of scarcity. Unless those charged with the design and construction of the works have made a special and very careful study of the lands, water supply, and prior rights thereto before beginning work, they have little positive information as to the real elements of value in their investment, and they have not always done this. The capitalists whose millions have been thus invested have naturally been more ignorant of the principles involved than the promoters and have often been deluded into believing that fabulous profits were to be realized through such investments.

In this manner a few irrigation works have been created throughout the arid region for whose existence there was no warrant whatever, whose priority rights to the use of water are practically worthless, either for the reason that the supply never existed, or because the available water had been appropriated long before the propositions

under consideration had been conceived and executed. These schemes not only work a permanent injury to the interests of legitimate enterprises in this field and to irrigation development in general, but are a menace to the future prosperity of the immigrant to the arid region, who, being unacquainted with irrigation practice and unfamiliar with the principles involved, can not intelligently determine the relative merits of the different propositions presented for his consideration, and thus frequently falls a victim to the misrepresentations of colonization agents, who, through the agency of elaborate and beautifully executed prospectuses, present the most alluring descriptions of the wonderful opportunities which await the settler who will purchase a quarter section of land and a water right from their companies—whose canal may, in fact, be perfectly dry for ten months in the year. Those who have been thus induced to invest their savings in these arid lands and worthless water rights may lose not only their money, but frequently many years of time wrestling with the adverse conditions growing out of their efforts to farm arid lands without a sufficient supply of water. They may succeed in eking out a precarious existence for several years, but are likely to find themselves becoming poorer with the advance of time, until at last, convinced of the futility of their efforts and the hopelessness of the prospect before them, they give up in despair, and, moving to some other locality, begin anew under more favorable conditions, with less money but with a vastly increased fund of information concerning the importance and necessity of a safe and certain water right in order to profitably conduct agricultural operations in the arid region.

THE DISTRICT SYSTEM.

Another method of constructing or otherwise obtaining a system of works for the irrigation of a given area of land is what is known as the "district irrigation system." The law under which this system is carried out originated in California, and although its general features have been copied, with greater or less modification of details, into the statutes of some other States, notably Idaho and Nebraska, the operations under the system have been almost wholly confined to the first-mentioned State. This district law is designed to secure the ownership and control of the water rights and canal systems by the people of the districts organized under its provisions. A district may be organized by a vote of two-thirds of its residents, upon an order of the board of county commissioners, which acts upon petition of a certain number or a certain proportion of the residents of the territory proposed thus to be organized as a district. After the organization, bonds for the construction or purchase of the works or property necessary to the object in view may be voted, which bonds become a lien upon the real property within the district. The interest is paid by assessments, similar to other public taxes, and the operating expenses are raised either by assessments, by valuation or acreage, or by tolls for the use of the water.

This system has many theoretical advantages, but its operation in California has not justified the prophecies of its advocates, and new districts are not being formed under it. The powers granted the districts seem to have been exercised in many cases with poor judgment, and heavy bonded indebtedness was incurred without corresponding advantages to the landowner in the form of water for his needs. In some instances the provisions of the law seem to have been taken advantage of for the purpose of turning unremunerative existing property and water rights into interest-bearing district bonds. Like other business enterprises, it depends for its success upon the judgment and honesty of those intrusted with the management of the business of the districts thus organized.

Each system and locality has its own peculiar features, and the best location and system is therefore a matter for careful investigation as to relative advantages, always having in mind, however, the certainty of the water supply, which is often the most difficult matter for the newcomer to get reliable information about. As this condition is the principal factor in successful farming operations, when it is satisfied such operations intelligently conducted will generally prove certain and remunerative under any of the plans herein described.

OPERATION OF CANALS.

The owner of an individual ditch operates it as he pleases, subject only to the State laws governing the diversion and use of water. But when several persons are interested in the same ditch, the necessity for some system of control arises. In the case of unincorporated community canals this control is secured by the selection of a water master, who is usually one of the owners, to have charge of the operation and maintenance of the system and the distribution of its water to those entitled to its use. It is on the large corporation canals, however, that the necessity for a careful system of operation and management is most apparent. Many of these canals are more than 50 miles long, and number their water users by hundreds. The Ridenbaugh Canal (see Pl. II), in the Boise Valley, Idaho, furnishes water to more than 500 farmers. The High Line Canal, in Colorado, has 433 consumers under it; the Loveland and Greeley has 257, and many other systems are as large or larger. It can thus be readily seen that the proper operation of such canals involves a very thorough business organization and careful attention to many important details.

The practical operation of corporation canal systems is, like their construction, under the control of the executive officer or officers of the company, but the representative with whom the farmer and irrigator comes into most frequent and intimate contact is the ditch rider, who is generally appointed by the manager or president. His duties consist in patrolling the ditch throughout the season of actual operation,

for the purpose of seeing that the works are in good repair, and to superintend the proper distribution of water to the various stockholders or irrigators from the system, and are somewhat similar to those of the water commissioner hereafter described, the main canal in this case taking the place of the stream, and the contracts or stock the place of the priority decree. In order to properly distribute the water the ditch rider is provided with a list of the persons having water rights from the canal, showing the amount to which each is entitled under his contract; or, in case of community stock companies, with a list of the stockholders and the amount of stock owned by each. Such a list furnishes the necessary data to enable him to distribute the water according to the quantity or proportion called for by these respective interests.

The larger irrigation systems generally have several distributary canals leading from the main one and following as nearly as possible the ridges or highest ground of the areas designed to be watered from them. Such distributaries obviate the necessity for such long and expensive individual lateral ditches as would be necessary if all such laterals diverted directly from the main canal. The expense of individual diverting works, as well as the danger attendant upon a multitude of diversions from the main canal, is also much reduced. The distributaries also generally follow the slopes of the ridges, and do not have a uniform light grade, as is the case with the main canals. Sometimes, also, natural drainage channels are followed, thus materially reducing their cost of construction.

At various points along the main canal or distributary lateral branches are diverted for conveying the water to the land of the individual consumers. As the amount to which each user is entitled is limited, it becomes necessary to place regulating structures at the points of diversion for the purpose of regulating the flow into these laterals. These consist of wooden, box-like structures in which sliding gates are placed, by which the size of aperture from the main canal is regulated and the flow of water therefrom controlled. (See Pl. IV.) Where considerable accuracy of results is attempted, there is also placed in the lateral ditch below the regulating gates a weir whose flow for all depths is computed and tabulated, and for the purpose of determining the depth at any time a graduated scale is so placed with reference to the weir that the depth can be conveniently and accurately read off. (See Pls. V and VI.) When it is desired to deliver into a lateral, so arranged, a given volume of water, it is merely necessary for the ditch rider to consult his weir tables and find the depth over this weir necessary to discharge the required amount. He then increases or lessens the opening from the main canal by moving the sliding gate in the regulating structure until the required depth over the weir is realized. This is the most important duty of the ditch rider, and for its proper execution he is expected to make a trip daily over the entire canal, or his division of it, and to examine and regulate the gate of every con-

FIG. 1.—DIVISION GATE ON IRRIGATION LATERAL NEAR ROSWELL, N. MEX.

FIG. 2.—DIVISION BOX ON IRRIGATION LATERAL, MONTANA EXPERIMENT STATION.

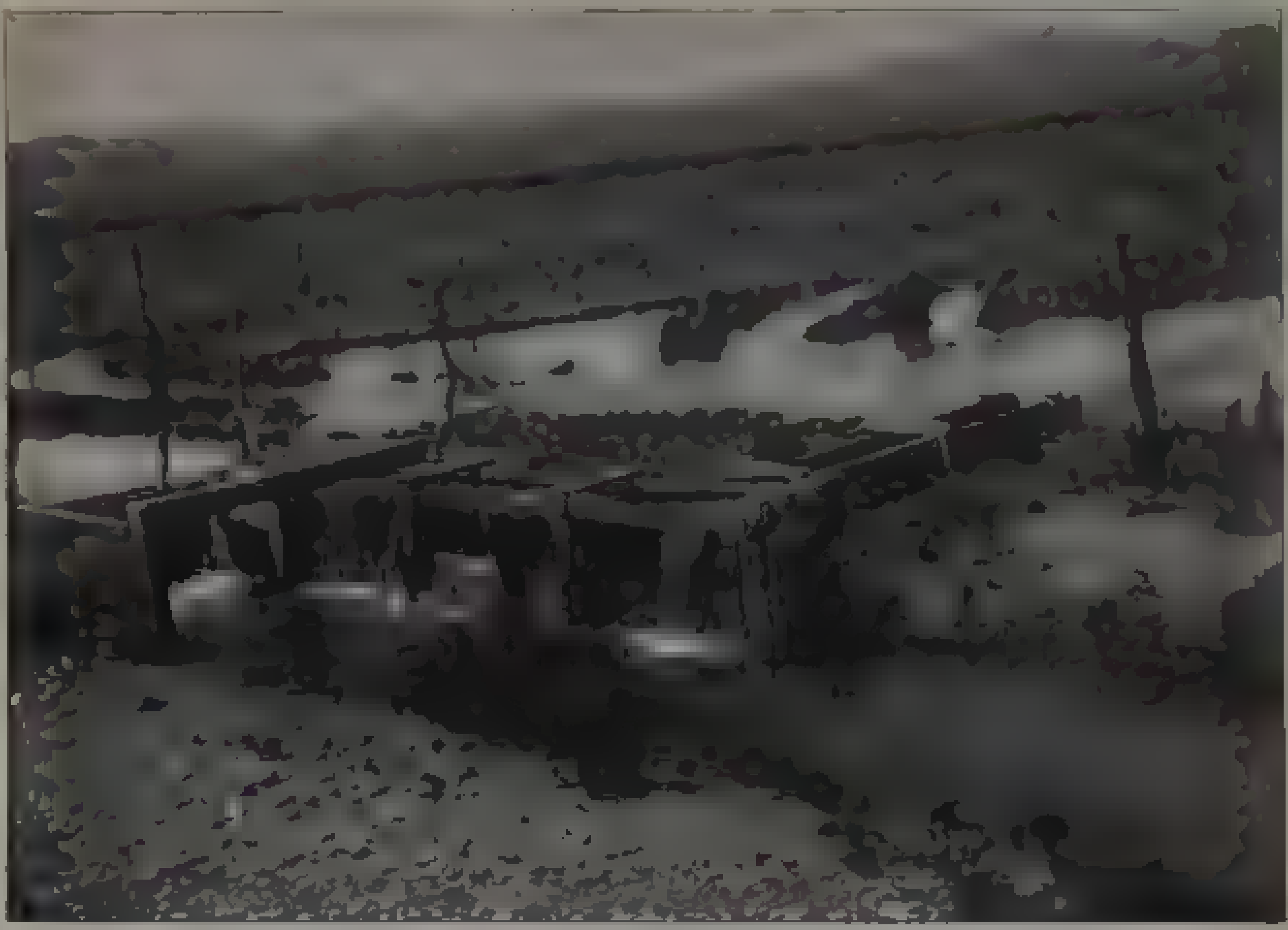

FIG. 1.—SPILL MEASURING WEIR.

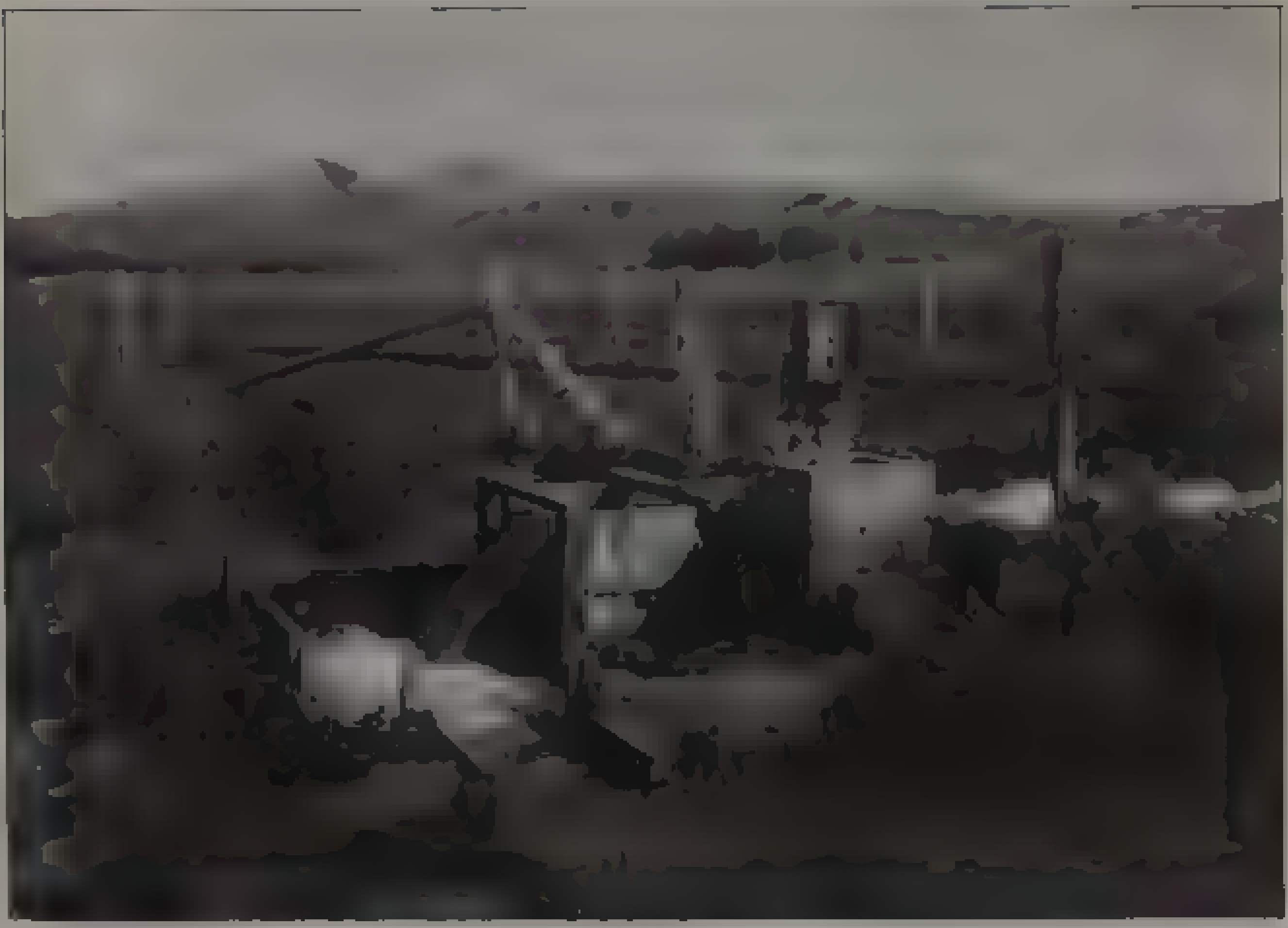

FIG. 2.—MEASURING WEIR WITH RECORDING INSTRUMENT.

sumer. He usually travels on horseback or in a two-wheeled cart, and carries a shovel, a hatchet, a small sharp-pointed bar, and frequently a number of empty sacks. The hatchet is used to repair structures and nail on boards which may have become loosened; the bar is for raising gates which may be difficult to move by hand; and the shovel and sacks are frequently required for the repair of banks and the stoppage of holes caused by the work of gophers, muskrats, and other burrowing animals, whose depredations frequently result in serious and expensive breaks in the embankments. The holes thus made are usually small and insignificant at first, but become rapidly enlarged through the erosion of the escaping waters, and if not stopped eventually result in a breach carrying away a portion of the embankment. The ditch rider, however, is expected to inspect the whole works under his charge daily, and usually detects the leaks by means of the escaping waters before serious results ensue. Upon the discovery of a leak thus caused, his first efforts are directed to the location of the point on the inside of the bank at which the water enters the hole. This is frequently detected through the eddy or vortex appearing at or near the opening. Having located this point, the orifice, if small, can be closed by pushing into the hole one or two empty sacks; if already too large to be closed in this manner, it can usually be accomplished by first filling a few sacks a half or a third full of loose earth and ramming them into the mouth of the opening into which the water from the ditch is passing. In this manner holes of considerable size can usually be effectually stopped in a few minutes.

The regulating gates before mentioned are frequently kept locked, as already stated, and the key thereto carried by the ditch rider. When, as frequently occurs, a water consumer has completed his irrigation and has for the time being no use for water, he may desire that it be shut out from his lateral. In such cases he leaves a note tacked to his head gate, requesting the ditch rider to shut it off at a specified time, and in the same manner notifies him to turn it on when he again needs it. The ditch rider gets these messages when he makes his daily round over the ditch.

Where a ditch does not exceed 12 or 15 miles in length one ditch rider is expected to patrol its entire length, but upon more extensive systems several may be required to perform these duties. Where there are several required the canal is divided into divisions, each of which is patrolled by a separate rider. In such cases the length of a division ridden by one man depends upon the character of the duties, varying materially with the amount of repairs, the danger of breaks and leaks, and the number of regulating gates to look after. The average length of a division is, however, from 12 to 15 miles, and the average compensation for the work ranges from \$50 to \$75 per month, out of which he must pay his own board and furnish and maintain his own horse and cart.

METHODS OF APPLYING WATER TO THE LAND.

Where an irrigator's land is contiguous to the main canal or distributary, he may have independent diverting works or lateral ditches. When, however, as usually happens, their position and the topography of the ground is such that a number of farms can be served by the construction of a single lateral, such is usually the method adopted. These laterals are usually constructed as partnership or community ditches, and are frequently extended and enlarged to meet the necessities of increased acreage and additional farms. Each irrigator is usually required to contribute in money or labor to the cost and maintenance of such ditches such a proportion of their whole cost as his water bears to the whole quantity of water carried, although sometimes the assessments are made also somewhat proportionate to distance from the head of the lateral. On most systems the company's responsibility ceases after turning into the head of such individual or community laterals a quantity of water equal to the aggregate amount to which all the users from it are entitled, the operation of the lateral and the distribution of water among the various consumers being left to be arranged by the interested parties. Where there are many users from a common lateral they usually select one of their number to take charge of the distribution of the water, whose duty it is to see that sufficient water is turned into the lateral by the company's ditch rider, and that it is equitably distributed among those entitled to its use. The proper location of these laterals is a matter of very great importance to economical and successful irrigation, and too great care can not be exercised in planning them, both to obviate the necessity for a multiplicity of ditches and to secure the best possible advantages for diverting the water over the lands to be irrigated.

FARMERS' DITCHES.

Individual farmer's ditches are required to convey the water from these community laterals to the places on the area to be irrigated from which it can be most advantageously spread over the ground for the irrigation of the various crops. These ditches should generally follow the ridges and higher contour of the area to be watered, and great care should be exercised in their location, so that all the land can be covered. Large areas of crops are frequently burned up through the careless and faulty location of these small ditches. Experience gained in such a manner is expensive, and too much care can not be exercised to secure their proper location in the first instance. The diverting works on these lateral and individual ditches are usually reduced copies of those used on the main canal, being in this country most often wooden boxes with sliding regulating gates. In the case of uneven and rolling ground it is frequently found necessary to divert water from several places on the main lateral to secure the proper irrigation of a single farm. The proper location of all distributing

ditches is possible only after a very careful study of the topography of the ground in each particular case.

The irrigator, having his stream of water in his own lateral, which is constructed across the highest part of the field to be covered, is now ready for its actual application to the growing crops. If his land is very favorably located, with comparatively uniform slopes, his lateral is probably in a straight line across the upper end or side of his field, with the greatest slope of the land at right angles to it. If his land has not so uniform a surface, his lateral may follow its irregular contour or be kept straight by diking it across the low places. In general the lateral ditches, from which actual application of the water to the crop is accomplished, should follow the line of least descent from the highest point of the field, the greatest slopes being perpendicular to them. There are several methods of applying the water to the land to be irrigated. Of these the two most common and generally used are the "flooding" and "furrow" systems.

FLOODING SYSTEM.

Under the flooding system small parallel ditches are constructed every hundred feet or so, according to the slope of the ground. Where the surface is broken they will be irregular and will follow along the ridges. These ditches should also have a slight fall, the steepest slope being at right angles to them. Such ditches are usually simply furrows made with a heavy moldboard plow, and, where the crop is grain, they are filled back by the plow before harvesting. These ditches, being cut at convenient points, allow the water to run out and spread over the adjacent land. The water thus released at once begins to follow the lines of quickest descent, and in so doing spreads out over the ground as it proceeds, dividing into numerous branches or rills as it increases its distance from the opening in the ditch. For the purpose of facilitating its spreading and to insure its thorough application to every portion of the surface, the irrigator follows its course, and by means of a long-handled shovel guides it to every portion of the field. This guiding is done by moving a few shovelfuls of earth here and there, and thus separating the various small rills and starting the branches in different directions. In this way the irrigator follows the water through the field and prevents its collecting in the depressions, leading it out upon such points as would without his assistance be missed by the water. Where only one operator is at work it is usually advisable not to make very many openings in the ditch at one time, since to do so may result not only in a waste of water through its concentration into larger streams which rapidly escape to lower ground where it may not be needed, but its concentration for long periods in the depressions of the surface is likely, through oversaturation, to damage the crop at those places. When the area which can be most conveniently irrigated from the openings thus made has been suffi-

ciently moistened, the latter are closed by throwing in a few shovelfuls of earth, and similar openings are made at other points, the same process being there repeated, and so on until the irrigation of the whole area has been completed.

The entire operation is characterized by much greater simplicity than would be supposed by one unfamiliar with the practice of irrigation, only presenting features of serious inconvenience when the surface to which the water is applied is very irregular and broken, the slopes steep, and the soil loose and friable to such an extent as to be easily eroded. Even under those circumstances no real difficulty is presented, though the work is thereby rendered slower and more tedious through the greater care required in handling the water, and because a large volume can not be handled at one time on account of the greater liability of washing away the top soil and thereby injuring the land. Fortunately, however, most of the farming land in the arid region has a comparatively uniform surface, and this difficulty is therefore not frequently encountered. The land so preponderates over the available water supply in most localities that neither the necessity nor the inducement exists for developing and improving lands of great irregularity of surface, and it is not generally nor frequently done.

Under this system an experienced irrigator can cover from 10 to 20 acres a day, the area depending upon the character of the land surface and the volume of water at his disposal. For such crops as grain, alfalfa, clover, and the various grasses—for everything, in fact, which is sown broadcast and is distributed uniformly over the surface—the flooding system is employed, and furnishes the best, in some cases the only, practicable method of applying the water; but for many other crops this plan is neither the most convenient nor the best method.

FURROW METHOD.

Under this method parallel furrows are plowed, leading from the ditch through the field between the rows of the crop to be irrigated. (See Pl. VII.) A small opening is made in the ditch to let the water into each furrow. A dam of canvas or earth is placed in the ditch just below the lowest furrow into which water is being run at the time, thus holding the water nearly level in that part of the ditch from which it is being drawn. Where the slope of the ground is excessive, these furrows must be run diagonally, or irregularly, in order to reduce their grade and thus prevent erosion of the soil.

In the case of fruit trees it is generally found desirable during very hot weather to prevent the water from coming into actual contact with the trees, because of the danger of scalding. Flooding the surface also results, in some soils, in baking and compacting the earth about the trunks and roots of the trees. To avoid these consequences the furrow system is employed, one or two furrows being plowed along each side of a row of trees, at a distance of two or three feet therefrom, and the water is turned from the ditch into these furrows and

FURROW IRRIGATION.

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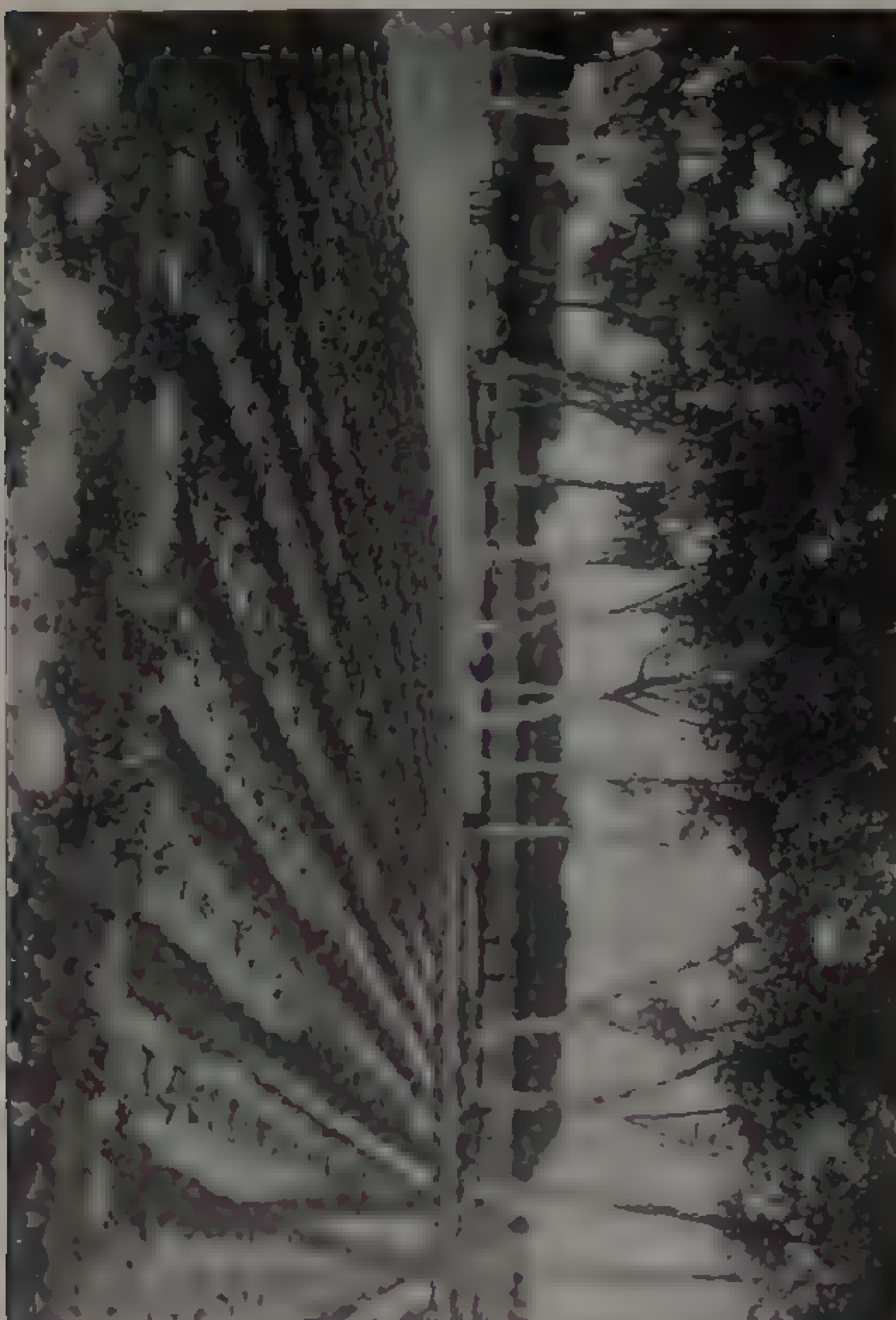

FURROW IRRIGATION.

permitted to traverse them slowly from end to end, thoroughly soaking the ground as it progresses, and reaching in to the roots without coming in contact with the stems above the surface. The necessary moisture is thus imparted without the wetting and subsequent baking of the surface which might result from flooding. When the trees are sufficiently irrigated, the water is turned out of these furrows and into others, the process being thus continued until the whole area has been served. The furrows are then filled in with a plow, the whole surface worked over with a cultivator, and no trace left of either the furrows or the application of water.

This method also requires the attention of an irrigator, to see that the proper amount of water is kept in each furrow, and that it does not break out and flood the surface in places, leaving the furrow beyond the break without water. One man can take care of a considerable number of these furrows at once, and under favorable conditions of surface and water supply can accomplish the irrigation of as great an area in a given time as by the flooding system.

This method is also applicable to the irrigation of corn, and in fact of any crop whatever which is planted regularly in rows, a single furrow between each two rows being generally used for such crops. When applicable it is the favorite method, both for its convenience and the economy of water thereby effected. But where the ground is very irregular this plan is often inconvenient, for the reason that the furrows paralleling the rows of crop would, upon such surfaces, be up and down hill, and would therefore not carry water. To make this method applicable in such cases it would be necessary that the rows follow approximately the contour of the ground, in order that the parallel furrows might carry water throughout their entire length. The irrigation of irregular surfaces, however, is generally conducted under the flooding system, except in localities where, as in parts of southern California, the value of the crop frequently warrants the expense of leveling off or terracing irregular surfaces, or the application of water through buried pipes, as it is arranged in the water supply of cities.

COMPARTMENT SYSTEM.

A modification of the flooding method is the compartment or check system of irrigation practiced in some localities, particularly in portions of Arizona. This consists in dividing the field to be irrigated into squares or compartments by levees or dikes of such height as to cause the water to stand over the entire area of the compartments at one time, the water being admitted to each compartment by means of a gate in the levee. The water is allowed to stand until the ground has become properly moistened, the time depending largely upon the character of the soil. The compartments or squares vary in size according to the slope of the ground, but are not usually more than an acre or so in area.

CHARACTER OF SUPPLY AND USE OF WATER.

SUPPLY.

Most of the streams of the arid region are comparatively small. This is the logical result of those climatic conditions which render the region arid. It is likewise a consequence of the proximity of their sources. More than half of the arid region is mountainous. Practically all its streams have their sources within its borders. They therefore consist of the headwaters of large rivers and a multitude of smaller tributaries. Most of the latter are short, and drain comparatively small areas before joining one of the larger streams.

All of the streams throughout this territory have rates of fall which are excessive in comparison with those found on the streams of the larger part of the humid region. The reason for this is found in the topography of the country. In the middle of the arid region are located the main ranges of the Rocky Mountains, which constitute the backbone of the continent, the divide between the Atlantic and the Pacific. The lands on both sides of this ridge slope rapidly, and the water courses, following generally along the lines of quickest descent, have corresponding declivities.

In the humid region the rivers are chiefly fed from rain, the highest water being generally experienced in February and March. Those in the arid region, as a rule, carry but little water at this season of the year, because there is little, if any, rainfall at this time. With few exceptions, there is no rainy season within the ordinary meaning of the term. The precipitation ordinarily occurs in the form of snow, and even this is not abundant except in the mountains. It is only in a few localities that streams in the arid region are appreciably and for considerable periods directly affected by the rainfall, such as southern California and parts of Arizona and New Mexico, where a more or less distinctly rainy season prevails and the streams usually carry their maximum volume in the winter and very early spring. But in the region under consideration in this bulletin, the source of supply and the cause of periodical high water is found in the fall of snow which occurs upon the mountain ranges during the fall, winter, and spring months. It is the melting of this snow with the advent of warm weather which causes the periodical rises, and it is therefore only during the spring and early summer that the water courses throughout the major portion of the arid region experience any considerable and permanent increase in volume of discharge, April, May, and June being the high-water months (see Pl. VIII). They always show high water at this time whether there has been any rain or not, the volume of flood depending upon the amount of snow to be melted, and its relative duration being determined by the warmth of the season and the consequent rapidity with which the snow disappears. Those streams taking their supply from the higher mountain ranges do not

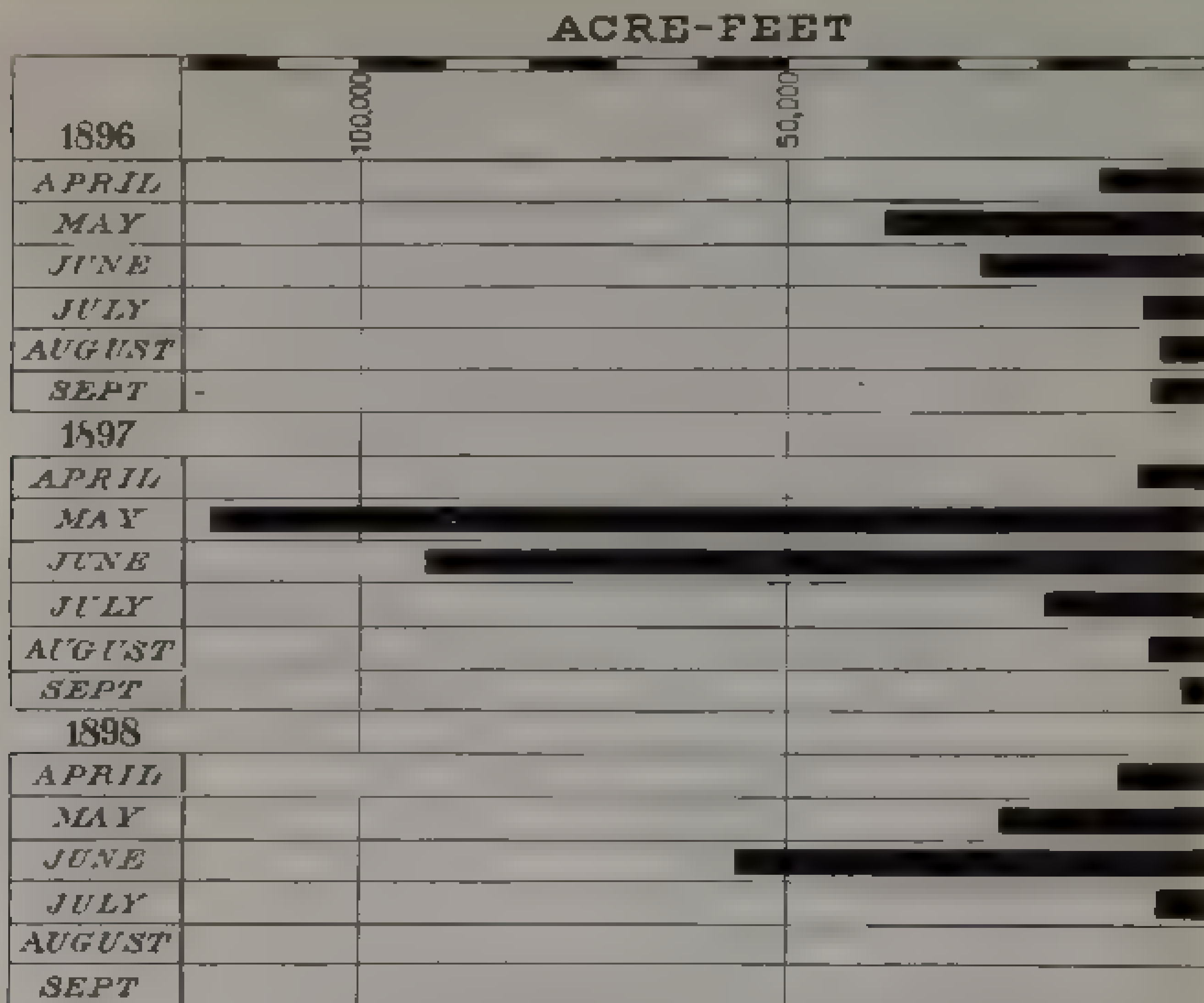

FIG. 1.—DIAGRAM SHOWING DISCHARGE OF LARAMIE RIVER.

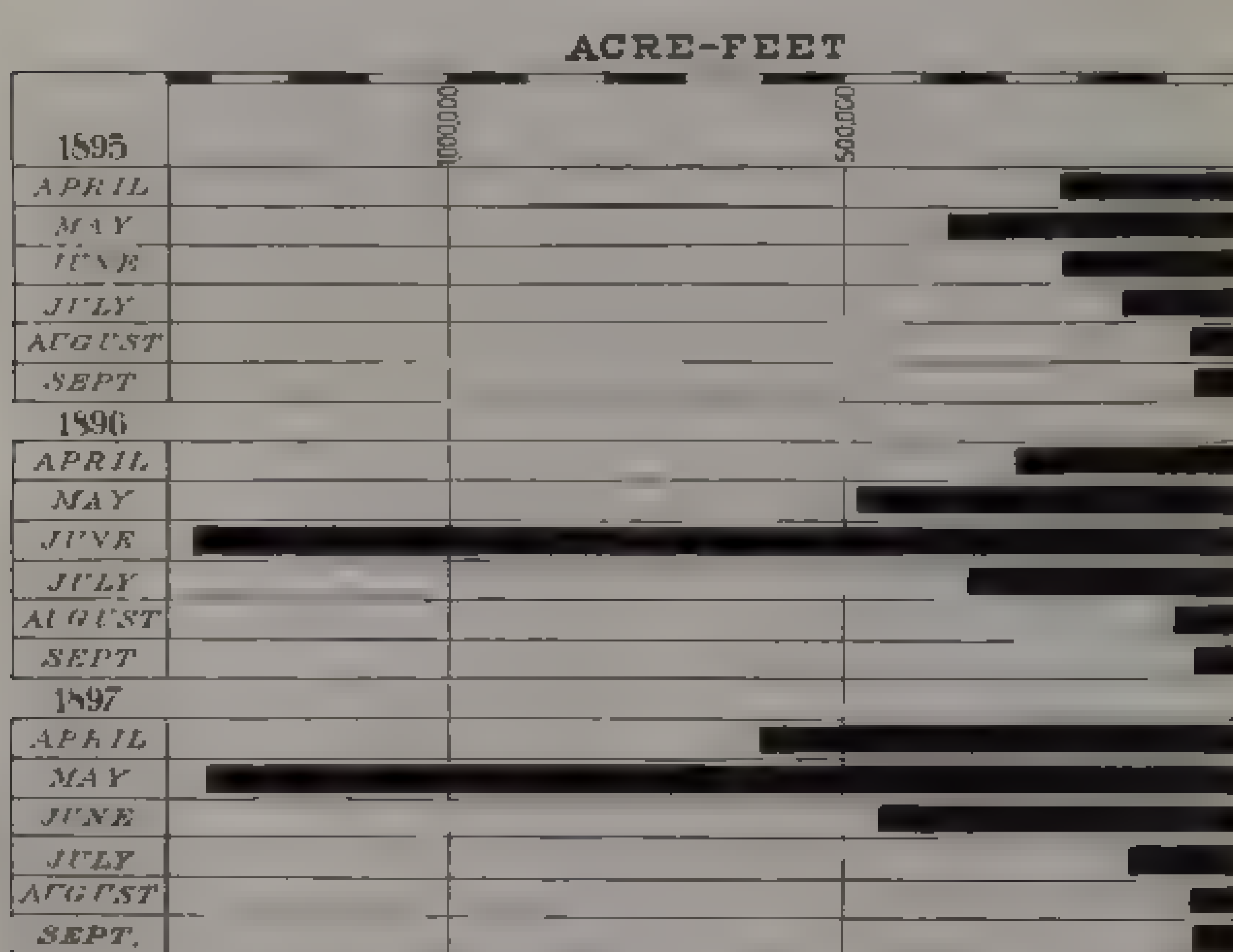

FIG. 2.—DIAGRAM SHOWING DISCHARGE OF BOISE RIVER.

definitely respond to the effects of warm weather until about the middle or last of April; the maximum is reached about June 1, and the complete subsidence of the flood occurs from July 1 to July 15. When the winter's supply of snow has disappeared the streams again shrink to the normal volume which characterizes their flow for about nine months of the year, the source of which consists principally of springs in the mountains and the melting of perennial snow banks whose sheltered locations in the higher ranges, where the intense heat of summer never prevails, causes their melting to proceed more slowly and gradually than at lesser elevations.

USE.

The irrigation season, or the period during which the application of water is practiced, varies within wide limits. In the southern parts of Arizona and New Mexico water is used throughout the entire year. The conduits in these localities are kept running winter and summer, being closed down only when a break or accident occurs, or when it is necessary to clean out their channels, or when (in the case of those of recent priorities) the stage of water in the streams whence their supply is diverted does not entitle them to its use. In the more northerly regions the date upon which water is turned into the conduits varies between March 1 and May 1, and it is generally turned off for the season between November 1 and December 1, depending upon the climate and the character of crops produced. In Colorado and Idaho these dates are fixed by statute, and are April 1 and November 1, respectively, though water may be turned in as much earlier and kept running as much later as the weather will permit.

The irrigation season is, however, with reference to the necessities of the crops under cultivation (except in the southern territory named), of shorter duration than that indicated by the dates limiting the flow of water in canals. The latter may be considered the limits within which the flow of water is practicable throughout the more northerly parts of the territory under consideration. With the exception of the grasses, and perhaps alfalfa, few crops require irrigation earlier than May 1, nor do they often require it later than September 15.

The quantity of water necessary or used for irrigation fluctuates during the irrigating season, but unfortunately the period of maximum use does not coincide with the period of maximum flow of the streams. On some streams the low-water flow is reached before the end of the period of maximum demand for water, and, as the flow available at such time limits the irrigating efficiency of the stream, the flood waters are of no material benefit to the irrigator. On other streams the maximum use is over before the complete subsidence of the high-water flow, some of which is consequently not utilized. The time of greatest need for water varies somewhat in different localities, but generally there is very little water used in April, and the quantity used in May

is relatively unimportant. June and July are the months of maximum use, and the use in August is usually considerably greater than that in May. After September 1 the necessity is again relatively unimportant (see Pl. IX).

Considerable data bearing upon this subject has been collected during the present year. Some investigations have been previously made by the State engineers and experiment stations in Colorado, Wyoming, Utah, and Idaho. From these results the relative quantities of water used during the different months may be approximated as follows:

	Per cent.
May	10
June	30
July	30
August	20
September	10

The proportion of the total annual discharge carried by the streams during the different months may be roughly stated as below:

	Per cent.
April	10
May	25
June	25
July	10
August to March, inclusive (eight months)	30

From an inspection of the above figures we find that the August flow of streams is the flow which limits their irrigating capacity, and that not more than about 20 per cent of their total annual discharge can be made available for irrigation from their natural flow. Of course this is only an approximation, but it is believed, from the data at hand, that this proportion will be found substantially true of most of the streams in the region under consideration.

STORAGE OF WATER.

If rivers were highest at the time when irrigators had greatest need of water the problem of utilizing the entire water supply would be much simpler than it is. In that case the area irrigated could be extended until the demand on the stream exactly equaled its supply and the entire flow could be utilized by diverting it directly from the river onto the land. This coincidence, however, does not occur. It has been seen that most streams begin to rise about April 1 and reach their highest point on or before June 1. The period when irrigation begins varies in different States and different altitudes in the same States and with the end of the spring rains. In Montana, Idaho, and Wyoming it is later than in Utah and Colorado. In the States first named there is little irrigation before May 1 and fully one-half of the water used is needed after July 1. Hence it follows that one-half of the annual flow of most rivers has passed the irrigator's head gate before the time of greatest need is reached, and a large percentage is gone before irrigation begins.

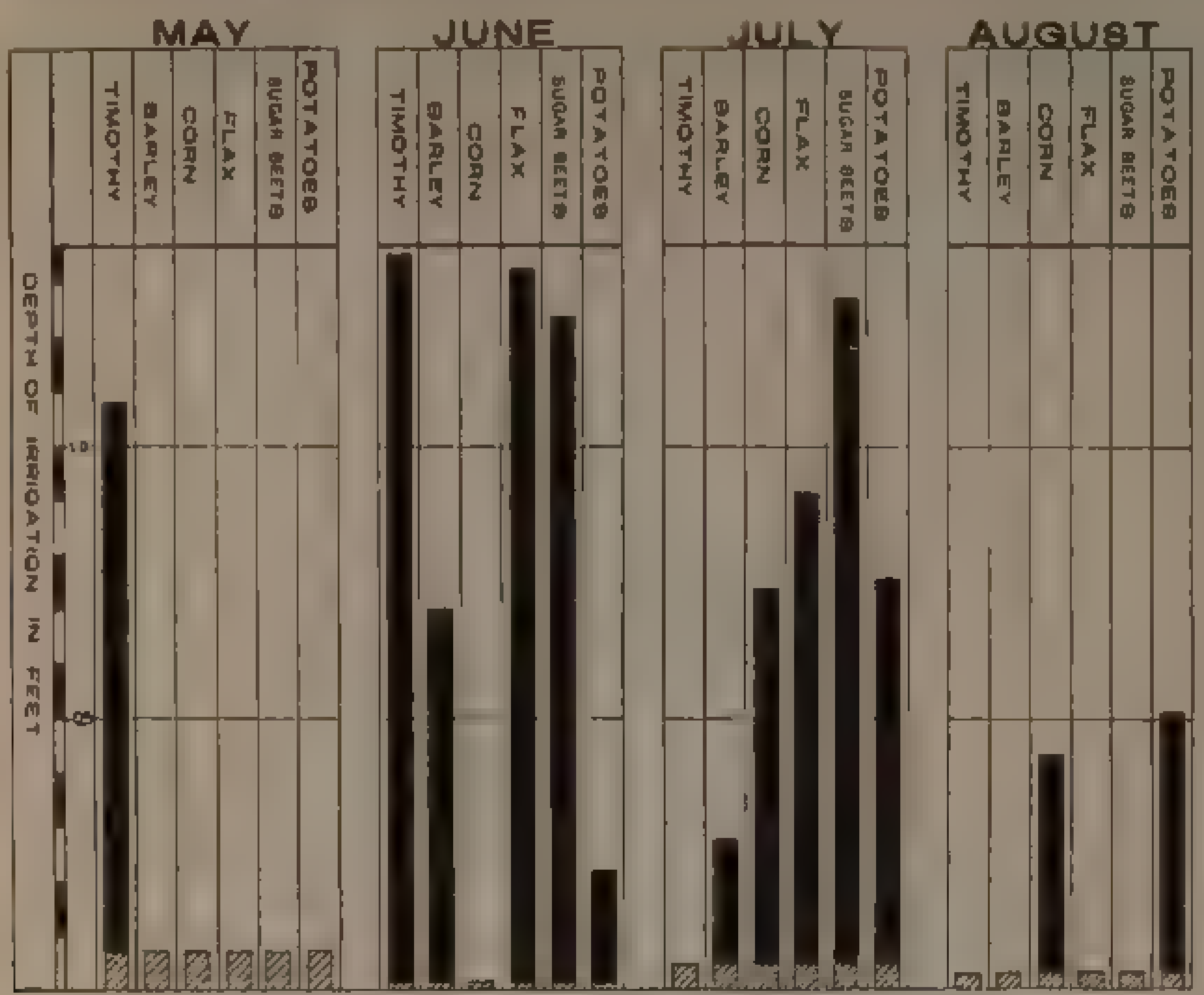

FIG. 1.—DIAGRAM SHOWING USE OF WATER AT WHEATLAND, WYO. (HATCHED PORTION REPRESENTS RAINFALL.)

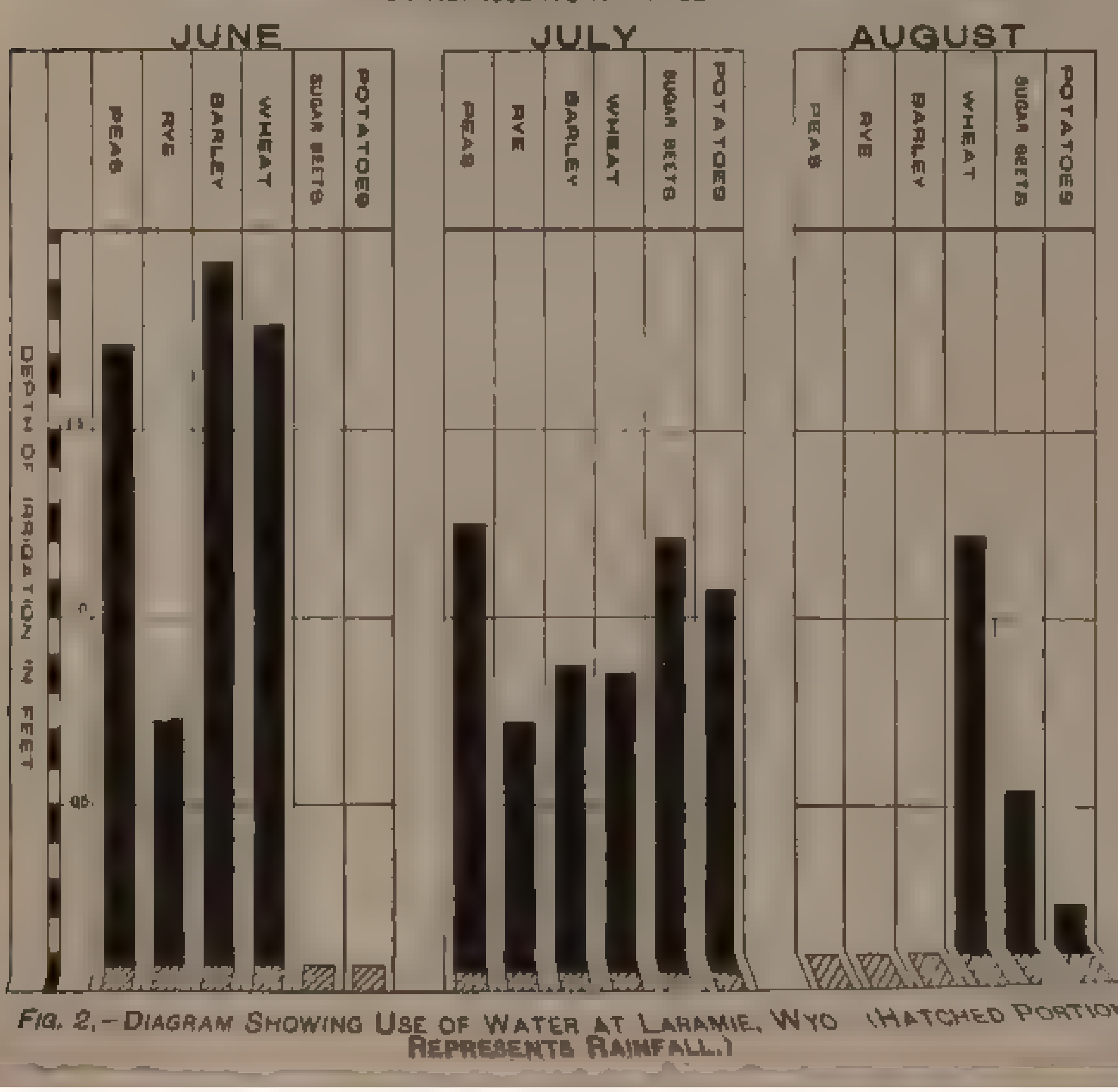

FIG. 2.—DIAGRAM SHOWING USE OF WATER AT LARAMIE, WYO. (HATCHED PORTION REPRESENTS RAINFALL.)

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The effect of this, as shown above, is to restrict the area which can be profitably irrigated to that supplied by the July and August discharge of streams, rather than to their discharge in the flood season, and to cut down the area which can be irrigated by the natural flow alone to from one-half to one-fifth of what could be reclaimed if the floods which now run to waste could all be stored.

Where the topography of the country is favorable this loss of water may be prevented or greatly diminished through the construction of reservoirs for storing the surplus during the early part of the season for use in the later months. In order to accomplish this, lofty and expensive dams have been built across the canyons of mountain streams. (See Pl. X.) The greater number of storage sites which have been utilized, and those which give the largest return for a given expenditure of money, are the lakes often found near the heads of streams and the natural basins or depressions frequently found in the valleys which border them. In some localities these basins are quite numerous and extend for a long distance from the stream out into the plains which border them. Others are broad openings or valleys in the mountains which were doubtless formerly lakes, but which have been filled by sedimentation. The basins found on the plains are more desirable, both because they are nearer the place where water is to be used and are freer from floods, and because it usually requires a smaller outlay to improve them. To do this requires the construction of a canal to fill them, and of outlet works for drawing off the water and transporting it to the land to be irrigated. Many of these basins are in the form of a great bowl, completely inclosed on all sides, so that no dam or embankment is required; but, on the contrary, there has to be constructed either an open cut or a tunnel through the surrounding rim, through which a pipe or some other form of conduit is placed for drawing off the water whenever it is required. In other cases the surrounding rim of the basin may not be continuous, low places existing which require the construction of embankments to retain the water.

The improvement of mountain reservoirs is essentially the same as that of those found on the plains, but the utilization of the water supply involves some problems not presented by those which exist on the plains. In the plains reservoirs the water is usually conducted directly to the lands, but in those of the mountains it has to be first turned back into the river and carried with the natural flow of the stream to the headgates of the ditches or canals through which it is to be diverted and used. This is necessary because of their distance from and their great elevation above the lands on which it is to be used. The Chambers Lake reservoir, at the head of the Poudre River, is 75 miles from the head of the ditch which is entitled to divert the stored water. The projected reservoirs at the head of Piney Creek, in the Big Horn Mountains, are from 15 to 40 miles from the ditches which are to utilize the water they will hold, and the construction of a complete storage system

for the utilization of the floods of almost any stream would require that some of the stored water be carried in the natural channel for long distances.

In many localities it is difficult or impossible to operate canals during the winter months. In such cases it is impossible to store the winter flow in reservoirs which lie outside of the channel of the stream and which have to be filled by means of ditches. It is only by means of lakes at the heads of streams, or the reservoirs created by dams along their channel, that the winter flow of these streams can be stored and utilized. Such reservoirs must be so constructed that the surplus water shall pass over the top of the dam or through a wasteweir provided for that purpose, as in no other way could the rights of prior claimants to the natural flow of the stream be protected. Whenever the stored water is needed it is turned out through large gates in the bottom of the dam. This lowers the water surface of the reservoir and ends the discharge of the natural flow over its surface or through the wasteweir provided. The question then comes as to the division of the natural flow and of the volume released from the reservoir, and this requires that measurements be made to determine the amount of each. This is usually accomplished by means of a weir or measuring flume placed immediately below the reservoir through which the water passes and by the construction of a similar measuring device to measure the natural flow of the stream above the reservoir. Where the stored water is diverted another measurement is required, the second gauging being for the purpose of determining that the amount taken out shall not exceed the amount of the stored water turned from the reservoir above.

Within the past ten years many of these basins have been improved and water has been stored with the most satisfactory and profitable results. Many irrigation enterprises with inferior priorities whose patrons prior to the enjoyment of this supplemented supply seldom were able to irrigate later than the 15th of June, have, since the construction of these storage works, been placed in a position of equality with those having the oldest and best priority rights.

With these benefits there are also complications. If a comprehensive system of storage is to be adopted it will doubtless greatly increase the difficulty of dividing water among the different claimants to a common supply and make it necessary to have additional legislation to define the character of the rights to these stored waters.

The benefits which have already come from the construction of reservoirs have been of the most substantial character, but their improvement and operation has also added largely to the annual cost of water and a canal with an early priority right which gives a definite and abundant water supply without their aid is much to be preferred. Reservoirs are simply a secondary means of utilizing waters which *otherwise run* to waste and they are the only safeguard of irrigators

on streams in which the natural flow has been overappropriated. Those familiar with irrigation know that this situation of affairs is of frequent occurrence and that there are few streams on which irrigation has assumed considerable importance in which late appropriators do not suffer as much from drought in July and August as do farmers dependent upon rainfall. In seasons where the winter snows have been heavy they can have an assured supply, but there are also years dependent upon rainfall when there is no lack of moisture. The discharge of rivers in the arid region varies more from year to year than the rainfall does in the section of country where crops are cultivated wholly through its aid. The discharge of the Laramie River in 1899 was five times as great as it was in 1889. An adequate system of storage will not only protect irrigators from the variation in supply from month to month, but will assist in reducing the fluctuations from year to year. It will enable the floods of years of large discharge to be held back for use during years of drought.

DUTY OF WATER.

No definite estimate that would apply generally to different localities and conditions can be made of the quantity of water required for the irrigation of crops. The amount varies with the locality; in a given locality it varies in different seasons, and at the same place and during the same season it varies with the nature of the soil, the method of application, the degree of skill exercised by the irrigator, and the kind of crop irrigated. Grain requires less water than alfalfa, potatoes need less than grain, and fruit trees less than any of them. For the ordinary farm products of the temperate regions—in Colorado, Wyoming, Utah, Idaho, and Montana—two or three irrigations or applications are usually required for the production of a satisfactory crop. The amount required for each irrigation will vary, within the States named, between 5 and 9 inches over the land.

These figures represent the results of the writer's observations during a long period of service in the distribution of water under many different systems of irrigation. This takes into account the losses due to seepage and evaporation from canals between the source of supply and the lands served, that resulting from the wasteful and unskillful handling of the water by careless or inexperienced irrigators, and various incidental sources of loss and waste; but as these factors of loss are generally to be found and are apparently inevitable under most of the existing systems of distribution within the States named, they constitute factors which can not be ignored in the proper consideration of the duty of water. That the service which water could be made to perform under the most favorable conditions of land preparation and skill in application would be much greater is a well recognized and conceded fact; and that improved practice in the design and construction of irrigation canals, increased intelligence and economy in the use of water, and more frequent and thorough cultivation of the soil will

eventually produce a marked effect in this direction are propositions that do not admit of reasonable doubt.

Then, too, the duty obtained from water depends very largely upon the method of its distribution. Under some canals compensation is made dependent entirely upon acreage cultivated rather than quantity used. Such a method is likely to promote wasteful use. In those cases where compensation is made to depend upon quantity of water used, the quantity is usually designated by a unit of continuous flow. This method also tends to promote waste during that part of the irrigation season when the maximum flow is not required. Neither of these methods will result in the fullest possible use of the water. In cases where a high duty and great economy in the use of water is necessary (especially where reservoir supplies are involved) the quantity should be expressed in terms of duration as well as volume of flow, as a cubic foot per second for twenty-four hours. This kind of a system and an equitable rotation in use among different users is the one best designed to promote the fullest possible use of the water.

This system of rotation is now practiced on many of the smaller streams and canals in time of scarcity, and will doubtless gradually become more general. The principle is that of periodical use of a certain irrigating stream by each owner in turn for a time corresponding to his proportionate ownership, and the periods of rotation are so arranged as to best promote the cultivation of the crops upon which the water is used. It is unfortunate that so many water-right contracts have established the more wasteful method. The time has come on many streams, and is certainly coming on most of them, when the highest possible duty of water will be necessary to the fullest development of farming operations. The method of distribution by rotation of use is quite generally practiced in Utah, where a very high duty, especially during the latter part of the irrigation season, is obtained under its operation. When there is a scarcity of water, the water master, instead of cutting down the size of the stream allowed to each irrigator, limits the time during which the stream may be used by him, thus giving him a stream large enough for economical irrigation for a length of time proportionate to his ownership of water or acreage to be watered. The length of time allowed each irrigator will, of course, decrease with the decreasing available supply from the stream, and the periods of rotation are arranged so as to give each user a fair proportion of night and day use.

This method is a very beneficial modification of the rigid doctrine of priority of right. Under it people are encouraged to irrigate liberally when there is a plentiful supply in the stream, and to exercise the greatest possible economy and skill in their operations when there is a scarcity. In Utah, where this commendable system is so generally employed, the doctrine of priority of right is modified by the division *of rights into* two classes, primary and secondary. The former class

includes all of the older rights on the stream to the extent of the usual low-water flow, and in times of scarcity all who hold such rights suffer equally, which is certainly more equitable than to allow a few of the earliest appropriators to control all of the flow at such times, to the ruin of the others. The necessity for careful measurements of the flow of streams through a series of years before the division of appropriators into classes can be made is of course apparent, and the lack of such reliable information may lead to errors of classification, but the plan has certainly many elements of justice not found in the rigid adherence to the doctrine of priority, and under its operation a greater beneficial use of the available water supply will result. To secure this fullest use of the water supply not only necessitates proper laws, but a careful and efficient system of administration and control of water distribution.

HOW WATER RIGHTS ARE ACQUIRED AND MAINTAINED.[1]

THE DOCTRINE OF PRIORITY.

The best lands, the best markets, and the most genial climate are generally found in the valleys, rather than at the headwaters of rivers. The first settlements are usually made on these valley lands. The first settler on a stream does not concern himself greatly about his right to its waters. He takes all he needs, or all there is, and in either case is neither helped nor hindered by wise or unjust laws governing its ownership. But the first settler is followed by the second, and as ditches multiply and the reclaimed area broadens there finally comes a time when there are more ditches than the stream will supply.

We have already seen that the streams of the arid region are small in most cases, carrying throughout most of the year a volume of water that is comparatively insignificant and often insufficient for the demand; and when the vast area is contemplated over which the condition of aridity prevails, and it is considered that scarcely any of it has any agricultural value without irrigation, and that the insignificant streams here found constitute the only source of supply, it requires no elaborate argument to prove that much the greater portion of this area can never be successfully or profitably cultivated—that most of it can in fact never be farmed at all. If the available water were equally distributed over all the lands of this vast territory, the amount would prove so slight as not to appreciably affect its aridity, and the whole would be wasted without producing any beneficial effect. In order, therefore, that the greatest good may be accomplished, its use must be restricted to such an area as it can reclaim in the best and most satisfactory manner. In practice this result can not, for many reasons, be perfectly attained, but it may, within reasonable limits, be approximated. If the streams of the arid region carried at all times sufficient

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[1] See also Appendix, p. 58.

water for the requirements of all the lands susceptible of irrigation from them, there would be no question raised concerning the right of priority to its use. All users would then be at liberty to divert and use as much as they desired, and one of the most fruitful sources of perplexity and controversy would be eliminated from the irrigation problem. But the preponderance of land within the arid region over the water available for its irrigation has naturally resulted in the attempt to reclaim many times the area which the meager streams can accommodate, resulting in conflicts of interest. Without some sort of general regulation and control the ditches farthest up the stream would take what they need, those lower down would take what was left, and on many streams the land first settled would have to go without water, and homes already established would be destroyed to create less desirable ones. Position would count for everything.

There are many reasons why such a condition of affairs has not been permitted in irrigated districts. As land is valuable only when it has an assured supply of water, respect for vested rights has led to the enactment of laws for the protection of the rights of those who first made use of the water. These laws are based upon the principle of priority of right, which decrees that of the various users and claimants of water those have the prior and best right who have first diverted and appropriated it to a beneficial use, and that rights descend to other claimants in the order of the dates of their respective appropriations. Without some such adjudication of these questions it is evident that agricultural development could not proceed; property rights in irrigated lands and reclamation works would not be secure, and the latter would therefore not be created. It would not be safe to invest labor and capital in the development and improvement of lands if the water rights upon which their value depends were not guaranteed the necessary protection.

The principle of prior appropriation appears to furnish the most satisfactory solution of the problems arising through the inadequacy of the water supply, and it is the one universally accepted and applied. Under the regulations based thereon no advantage is gained through position upon a uniformly-flowing stream, nor does the magnitude or relative importance of the improvements affect the right. A consumer near the headwaters of such a stream must yield to the prior appropriator who diverts his water at a point a hundred miles below. The powerful corporation which has spent millions in the construction of its works must close its headgates and permit the precious fluid to pass on to the humble individual who constructed his ditch first, and thereby acquired the prior right to its use. Few streams, however, have anything like a uniform flow through their entire course. Seepage water from irrigated lands above, as well as surface and subterranean flows, are often of great importance on the longer streams and of material

benefit to the lower appropriators. Streams can not, therefore, be generally considered as channels of uniform flow where each appropriation is valuable according to its priority number; but conditions are often much complicated by losses and gains in different portions of their course, and the determination of priorities and the fair and just distribution of the water under them is consequently often rendered difficult and perplexing.

Priority rights to the use of water, however, are most important and far-reaching in their connection with agriculture in the arid region and merit the closest investigation, not merely on the part of the capitalist who contemplates the investment of his millions in works of reclamation, but by the individual settler and farmer who proposes to locate in this region and devote his energies to farming under the practice of irrigation.

In order that prior rights may receive the respect and protection to which they are entitled, and for the purpose of furnishing information concerning the unappropriated water supply of the different streams for the benefit of those who may contemplate availing themselves of its use, it is necessary that the facts concerning the water supply of all streams, and the effective appropriations therefrom, be made matters of public record, readily accessible to the general public and to those who may be interested in this question. It is the absence of such a record that has led to many of the abuses and evils from which irrigators suffer at the present time. For this the early settlers are probably more responsible than anyone else. The old settler, as a rule, has resisted legislation for the definite enforcement of rights. He has done this for two reasons. As a rule, he claimed more water than he used or needed, and he feared that any adequate control would deny him the title to all he claimed. The next reason was his antagonism and jealousy of the larger and later ditch companies. The second obstacle to proper laws for the recording or enforcement of rights is the opposition of the later appropriators. The corporation ditch owners are not, as a rule, users of water. They build canals to sell water. When their work began there was a chaotic condition of law and of public sentiment regarding what constitutes an appropriation. It seemed to be in the interest of the larger companies to claim that the size of the canal determined the amount of the right, no matter whether the water was used or not. In many cases not even the size of the canal has been the standard, but the flexible and expansive "intent" of its owner. The fact that the large corporation, the small individual ditch, and the farmers who use water from both are all claimants for a common supply, having interests that are more or less antagonistic, has led in every State to more or less indefinite declarations, and in some of the States prevented any legislation whatever,

METHOD OF APPROPRIATION.

The laws of most States require that any individual, association, or corporation desiring to appropriate any of the public water of the State must file for record with some public officer (generally the county recorder of the county in which the diversion is proposed to be made) a statement setting forth the quantity of water claimed and more or less definite information in regard to the location and character of the proposed use. If within a reasonable period, the limits of which are usually fixed by law, the actual diversion has been accomplished and the water applied to a beneficial use, the claim becomes definite and effective and the steps taken to acquire the water right becomes a matter of record, which is designed to furnish specific information as to the volume so appropriated and date of its appropriation.

As a matter of fact, however, many such recorded claims are purely speculative and have never been perfected at all. Few have been perfected for more than a small proportion of the quantity claimed in the record. So an examination of the recorded claims to the waters of any stream really gives very little actual information in regard to appropriations from it. With the exception of Wyoming and Nebraska, the State exercises no control over the perfecting of an appropriation, and the determination of the priority and volume of an appropriation can be had only by a suit at law resulting in a court decree establishing them. Such suits generally result when the water of a stream is insufficient to satisfy the demands of those who claim rights to its use. These court decrees are based upon the testimony of the interested parties as to the quantity of their appropriations, and have often been rendered under a misapprehension of the facts and in ignorance of the actual conditions. Many of the earlier decrees were rendered before the very great importance of the questions involved was realized. The results have not generally been satisfactory, and have usually been the giving of excessive quantities of water to the various claimants, resulting on many streams in a few of the earlier priorities controlling all of the low-water flow. That a strict State supervision, and examination of ditches and area irrigated is necessary to a just determination of rights and a proper protection of public interests in the water, is now apparent to all students of the subject. Existing methods are leading to much litigation on the overappropriated streams, efforts being made in some cases to overturn existing decrees. The conditions may be best shown by a few brief quotations. Hon. V. A. Elliott, formerly a district judge in Colorado, in a brief in the supreme court of that State, says:

> In the earlier adjudication of priorities, there was little or no contention between rival claimants. People seemed to think all they needed to do was to "prove up" their appropriations and get decrees for as large quantities of water as possible, * * * notwithstanding the fact that the amount of the appropriations decreed from some of our natural streams was four times as much as the ordinary flow of the water in such streams.

In another case in the same court he says:

Excess priority decrees are a crying evil in this State. From every quarter the demand for their correction is strong and loud. * * * Their continuance is such a hardship that litigated cases will be continually pressed upon the attention of the courts until such controversies are heard and settled, *and settled right.*

The State engineer of Idaho, in his biennial report for 1895–96, states:

The tendency toward excessive decrees has certainly retarded settlement and cultivation in some cases on account of the waters of the stream not being so decreed and distributed as to serve the greatest possible area of land.

Similar conditions exist in the other States where the determination of these important questions are left to the ordinary process of the courts, almost endless litigation and enormous expense to the litigants resulting. Sometimes, too, the decrees are indefinite, the method of measurement prescribed by the courts being often incorrect or uncertain, still further complicating the decrees.

On the other hand, in those States (Wyoming and Nebraska) which have a board of control for the settlement of these questions, there has not only been very little litigation, but the adjudication of rights has been comparatively inexpensive, as well as fair and equitable, as shown by the very few appeals from the decisions of the board. This is shown by the following quotation from the latest report of the secretary of the Wyoming board of control:

In other States irrigation matters have proved a fruitful and vexatious source of litigation. Not so in our State. Whenever tested the courts have upheld the actions and decisions of the board of control. It is a source of great satisfaction to the members of the board that the irrigation litigation that other Western States are burdened with does not exist in Wyoming.

In this State the water is decreed to certain described land, and is by law forever inseparable from it. Speculation in water rights apart from the land is therefore prevented.

HOW RIGHTS ARE ENFORCED.

These court decrees, or (in Wyoming and Nebraska) the orders of the boards of control, as to priority of the various water rights and the volume of water of a stream furnish the basis for a distribution of the water in times of scarcity. The enforcement of these rights of priority and the distribution of water under them is accomplished by water commissioners or water masters. In some States, as Colorado and Wyoming, these commissioners are appointed by the governor and are under the general direction of the State engineer. In others, as Idaho and Montana, they are appointed by the judge of the court rendering the decree, and are responsible for the proper performance of their duty to no other authority.

That this supervision of the distribution of the water may be effective in detail, it becomes necessary to police and patrol the streams from which it is diverted. To this end it is the duty of the water com-

[illegible]

... may [illegible] return to the vicinity of [illegible] perhaps travel even farther than before to close the gates. If the stream [illegible] but continues to go steadily down, the closing of gates likewise continues until only those remain open whose priorities are the oldest and best, and the aggregate amount of which rights does not exceed the quantity of water flowing in the river at its lowest stage. These, of course, are never molested, and the farmers whose operations are conducted under these canals are fortunate. They are always prosperous, because they always get plenty of water and therefore invariably have good crops.

If the river fluctuates rapidly, sometimes rising and again falling, the water commissioner has an even more difficult task, for in addition

to the work of closing gates, he has, with each rise, to see that the gates of those thus becoming again entitled to water are raised, which is a matter of quite as much importance as that of closing those of the appropriators who have not the right to its use. In the time of scarcity he has in the discharge of his duties not only the right to close the head gates of those not entitled to water at the time, but the authority to lock them down. When this authority is exercised he usually posts a written notice upon the gates so closed, which gives notice that the same are under the control of the water commissioner and must not, under the penalty of the law, be opened or interfered with except by his authority. Such interference constitutes a misdemeanor for which, upon conviction, the offender may be punished by fine or imprisonment, or both.

Many irrigation enterprises have several priorities to the use of water, bearing different numbers and becoming effective under separate dates. This results through enlargement of the works subsequent to the date of original construction. When a canal or other irrigation enterprise is constructed, it receives a priority right bearing a given number and recorded under a date which is usually coincident with the beginning of construction of the works. If, upon any date subsequent thereto, the owners or operators of this enterprise enlarge the works so as to divert and use a larger volume of water it becomes necessary, in order to secure protection in the use of the additional right thus claimed, that a decree of the court be obtained establishing the priority right pertaining to the additional supply thus provided for. This priority will take its proper consecutive rank with relation to other prior appropriations, will be recorded under its appropriate number, and will bear a date registering the time when it became effective. This date will be, if the work of enlargement has been prosecuted with reasonable diligence and application has been made of the water to a beneficial use, coincident with the date upon which the work of enlargement was begun. If between the date of original construction and that of the enlargement no other appropriations have been made from this stream, the priority numbers of these two decrees will be consecutive, and the two priorities may be treated practically as one, though bearing different dates and numbers. When, however, between these dates of original construction and subsequent enlargement other appropriations intervened, these take precedence over that for the enlargement of the work under consideration, and, while junior and inferior to the original appropriation, are senior and superior to that secured by virtue of the enlargement. This enterprise will then have two separate priorities, bearing different numbers and dates, and having different degrees of effectiveness. As a result of this, at times when the water supply is deficient, one (the earlier) of its priorities may be effective, while that due to the enlargement is not recognized.

Some canals have several of these successive priorities with other

rights intervening. It thus becomes necessary that the water commissioner know not only the full carrying capacity of each conduit diverting water from the streams within his division, but that he also know the amount being carried at any given depth of water. The canals are usually rated or gauged by the State engineer's office, and the water commissioner is given a table of these ratings. For convenience in gauging each canal company is required to have placed in its canal, at or near its upper end, a flume or rating weir which is used by the State engineer in such gaugings, and his ratings or tables of discharge for given depths are based upon measurements made in this structure. By means of these tables the water commissioner can, by observing the depth of water within this structure, determine the amount passing at the time, and is thus enabled in times of scarcity to accurately shut off one or more of the junior appropriations without interfering with those of earlier dates which may be still effective.

NECESSITY FOR DEFINITE LAWS.

While the doctrine of priority of right is necessary to protect the appropriators and to make possible a system of distribution, the fullest beneficial use of the public waters, as well as the interests of the later appropriators, demands that such rights, on overappropriated streams, be subject to reasonable and careful restriction and public control to prevent an unnecessary use or waste of the water. A record of the flow of the different streams is very important in this connection, and one of the duties of the State engineer's office is to make and record the results of periodical or daily gaugings of the different streams of the State from which water is diverted for agricultural or other uses, the object of these measurements being the determination of the volume of their discharge at various depths, the amount generally available for use during the different months, and the total run-off for each year. Records of the results of these operations are preserved for future reference and furnish most valuable information concerning the water supply, of great service to those investigating the merits of irrigation enterprises already created, propositions under contemplation, construction of storage works, etc.

The laws and customs regarding appropriation and distribution of water are generally in an unsettled condition, and differ materially in different States. In some States, as Utah, water is clearly recognized by law as being personal property, subject to transfer and sale separate and apart from the land it irrigates. In others, as Wyoming, the directly opposite doctrine is laid down, land and the water used for its irrigation being inseparable. In still others, as Colorado, the question is not definitely settled by statute and the decisions of the courts have not been uniform, the later decisions seeming to treat water appropriated for irrigation as personal property. This important question ought to be definitely settled, and after that is determined it ought to be established so that everybody could know exactly how an appro-

priation is acquired and when it is completed. Every man who owns an irrigated farm or every settler who wishes to own one ought to be able to ascertain exactly what the water rights of a particular tract of land are. Where the ownership of the land, the ditch, and the appropriation are all centered in one individual, this is not of much importance, but when it is possible for one party to own the appropriation, another the canal, and still another the land, as it unquestionably now is in a number of the arid States, the uncertainties of the situation and the possibility for litigation are so great as to make those who expect to be farmers and nothing else hesitate to take their chances under them.

CONTRACTS BETWEEN CORPORATIONS AND IRRIGATORS.

We have explained (p. 18) the four general plans by which individuals, communities, corporations, or districts organize and operate to provide a water supply for irrigation. In three of these the individual irrigator has an interest of ownership in the water right and in the system of works for its distribution. Under the corporation plan, however, the water user has, as a rule, neither an ownership in the works nor in the appropriation of water. Where the irrigator is also the owner of the ditch by means of which the water is diverted from a public stream, the restrictions on his right to water are simply those imposed by the priority of his appropriation and the provisions of the State law for its enforcement. But under the corporation canal he is subject to the limitations of his contract and the regulations of that canal in addition to the limitations imposed by the irrigation laws. In the present chaotic state of legislation and of public sentiment it is difficult to make a positive statement in any State regarding the exact limitations of an appropriation, or to definitely describe and define the nature of the irrigator's rights under a water right contract with a canal company.

In the first place, outside of Wyoming and Nebraska the appropriations so far as made go to the ditch companies, not to the land reclaimed nor to the owner of the land irrigated by them, and each ditch company, subject to State laws, fixes the conditions under which the water so appropriated shall be disposed of. The rights of the individual settler or the rights of a particular tract of land are not, therefore, determined by the State irrigation laws, but by a corporation acting under those laws. In many cases the contracts of these corporations place restrictions on the use of water which they deny govern its appropriation. Some of these restrictions are wise and show a better appreciation of what the laws governing an appropriation should be than have either the courts or lawmakers in their efforts to define it. In other cases the conditions of these contracts are wholly one-sided, unfair to the irrigator, and a menace to agriculture. Their reform is necessary to either the stability of the irrigated farm or the peace and content of the user of water.

KINDS OF CONTRACTS.

When the corporation is the agency through which the water is diverted and conveyed to the land, it becomes necessary that the water user enter into a contract with the latter which defines the obligations and liabilities assumed by both parties thereto. Of these contracts there are two generic forms that are radically different and applicable to two distinct plans of procedure, designated respectively as the "perpetual" and the "annual" plans. Under the former the corporation agrees that upon the payment by the water user of a stipulated amount of money it will divert and deliver to a certain point a specified volume of water for the irrigation of certain lands, which service will be repeated in perpetuity throughout each irrigation season. These contracts frequently take the form of a deed for a perpetual right to water. The second plan is generally termed the rental system, as the corporation agrees to deliver and the settler to take and pay for water only during the irrigation season under consideration.

In the contract under the latter plan no provision is made for the delivery of water beyond the limit of the specific year and season for which it was made, and though the consumer will probably, and usually does, use the water every year, he must annually renew his lease or enter into a new and distinct contract at the beginning of each irrigation season for the water which he intends to use. The principal obligation assumed by the water user under this form of agreement is the payment to the irrigation company of its charge or rental price for its delivery. In return for this annual payment the corporation agrees to deliver the specified amount of water continuously through the irrigation season under consideration, or throughout that part of the season when a supply in excess of that required for the necessities of prior appropriators is found in the stream from which the diversion is made. For the result of a shortage in the stream the company assumes no liability, the individual consumer of water being expected to satisfy himself as to the sufficiency of its priority right before locating under the system, and being compelled to submit to the consequences of his failure to do so when it may have developed later that the supply is unsatisfactory. The company agrees, however, and under the terms of its contract is required, to maintain its conduits in good order and repair, and to be at all times prepared to deliver water whenever the supply is available.

Where the "perpetual water right" plan is followed a contract is issued in which there is no time limit to the obligations and liabilities assumed. It is contemplated that the water will be required and used every year and for all time. It provides that the irrigation company or its successors will maintain its conduits and other works in good order and repair for the carriage and delivery of water during each and every irrigation season, and that it will at all times be prepared to and will deliver to the lands specified in the contract the quantity therein stated, except when, through scarcity of the supply, the water is

required and taken by prior appropriators who have a superior right to its use, or when unforeseen and unavoidable accidents, resulting in injury to or destruction of parts of its works, make the performance of this service temporarily impossible. It is provided, however, that when unavoidable accidents of this nature occur the company must exercise every reasonable diligence in their repair in order that the delivery of water may be resumed with the least possible delay.

UNIT OF MEASUREMENT

Some irrigation companies sell the right to the use of water by the cubic foot per second, or "second foot;" others supply it by a unit designated as the "inch;" a few determine the quantity by a certain depth over the area irrigated, while the contracts of many companies guarantee the delivery of sufficient water to properly irrigate the described land, not exceeding a certain quantity per acre.

A cubic foot of water per second (second foot) may be defined as the amount which would be delivered by a rectangular trough 1 foot wide and 1 foot deep, running level full, the water moving at a uniform velocity of 1 foot per second of time. Or, again, it is the quantity which, if flowing continuously and uniformly from a spout, would fill a cubical vessel 1 foot wide, 1 foot deep, and 1 foot long (7½ gallons) in exactly one second.

The "inch" has a widely different meaning in different localities, and is not, like the "second foot," a definite quantity. It is measured through a square or rectangular opening, with the water in the source of supply standing a certain number of inches above the top of such opening. The number of inches being discharged is equivalent to the number of square inches in the area of the opening, the variation in different localities being due to the varying regulations governing the form and size of the opening, and the height or "head" of the standing water above it. That employed generally in the agricultural regions of Idaho and California (4 inch "head") is equivalent to one-fiftieth of a cubic foot per second. In Montana 40 statute inches are declared by law to equal 1 cubic foot per second. In Colorado also, the inch is defined by statute and is called the statutory inch, of which 38.4 are equivalent to 1 cubic foot per second.

LIMITATIONS OF CONTRACTS

The consumer is limited to the use of a specified maximum volume of water, more than which the corporation is not under any circumstances required to deliver; which quantity, however, may be and on many streams frequently is materially reduced during the low water period, except under those systems having the best and oldest priorities, whose patrons may enjoy the benefits of a full supply continuously throughout the irrigation season. These contracts usually stipulate that when, because of shortage in the stream, the supply is less than that called for by the outstanding contracts, the water available must

be prorated among the different contract holders in the proportion that each claim bears to the aggregate amount called for by all the contracts. For example, if a given irrigation canal has outstanding contract obligations calling for the delivery of 100 cubic feet of water per second, and the volume flowing in the stream from which the diversion is made is such that after the rights of prior appropriators have been honored only 50 feet remain available to the canal in question, each of the contract holders is given just half the maximum quantity of water for which his contract calls. In such cases no reduction is made in the amounts payable to the irrigation company, the latter assuming the position that its obligations have been carried out and performed when it has maintained its works in good order and condition, has been prepared at all times to convey water in the quantities contracted for, and has so conveyed it at all times when water, unappropriated by consumers having prior rights to its use, was available in the stream.

There is sometimes a provision in these contracts, under which the corporation agrees that when a specified percentage of the carrying capacity of the canal or other conduit has been disposed of through the sale of water rights, the enterprise will be reorganized, the paid-up water-right contracts outstanding will be taken up, and in lieu thereof certificates of stock will be issued to the former contract holders, to each in the proportion which the quantity of water called for under his contract bears to the total quantity represented by all of the contracts. The management of the affairs of the enterprise will then be turned over to these new stockholders. When this reorganization has been effected the enterprise assumes the form hereinbefore described, in which the stockholders are the actual users of the water. This is the usual provision in the contracts in those States (Wyoming and Nebraska) where the appropriation of public water is vested in the land irrigated by it, although it is often found in contracts issued in other States.

COST AND CONDITIONS OF RECLAMATION.

A serious mistake is involved in the assumption that the immigrant to the arid West has only to homestead or purchase a quarter section of land and at once become a prosperous and successful farmer. This would be possible if the land secured were at the time of its acquisition developed and highly improved. Lands of this description are available throughout this region, but in most cases they command prices equal to those prevailing in the humid States for lands of similar quality and equal productiveness and proximity to markets. They are, therefore, out of the reach of settlers of limited means. Those offered for sale by the various irrigation companies are almost without exception raw and unimproved prairie lands, upon which much development work must be done in the way of breaking and subduing the native

sod, leveling, erecting fences and buildings, constructing ditches, etc. These lands can usually be bought at very moderate figures, and upon very favorable terms. They are, as a rule, capable of being developed into farms of superior fertility and productiveness; but they can be brought into this condition only at the expense of great labor and a considerable investment of time.

Similar conditions prevail in those cases where the settler homesteads land from the Government and creates his own water-supply facilities under the individual plan described in previous pages (p.18). His land in this case, nominally, costs him nothing, and if he does the work of development and improvement himself he may get along without the expenditure of much actual money; but if he should figure up the cost, at its market price, of the labor and time which he has devoted to the work, he would discover that the farm thus acquired, practically without cash, had in reality involved an expenditure largely in excess of anything which he had anticipated at the outset, and he will then understand why well-improved farms in the arid regions, which originally cost nothing for the raw land, sell for as much as similar farms in the well-settled States of the humid region. Nor is there any good reason why they should not do so, since a fertile, well-improved, and well-located ranch in this region, which has a satisfactory supply of water for irrigation, will, under skillful and intelligent management, as a rule, yield a profitable return upon the investment represented by its cost; and this is especially true in those cases where the actual settler acquires raw lands and improves them himself through his own labor and without the expenditure of cash. The labor and the hardships involved may appear trying and burdensome for a while during the pioneer period, and before the development is completed, but past experience indicates that where the conditions are favorable, the results will, in the end, generally be satisfactory. Where failures and disappointments occur, they are usually the result of an insufficient or unreliable water supply.

The value of farming lands and water rights varies so greatly in different localities of the arid region that it is extremely difficult to give any average price that will not be misleading. The price of raw land with a perpetual water right under the larger enterprises is usually between the limits of $15 and $35 per acre, with the annual maintenance charge on the water right varying from 50 cents to $1.50 per acre. From 40 to 80 acres is generally regarded as the proper acreage for a person of limited means, and in ordinary farm crops can be farmed principally by his own labor. The payment for land and water right is usually extended over a period of five years or more, the time of the second payment being often two years after the first, thus enabling the farmer, under favorable conditions, to make his second as well as succeeding payments from the results of the cultivation of his land.

Taking $20 per acre as cost of land and water right, and $1 per

acre as the annual maintenance charge, the first year's expenses on an 80-acre tract of this kind of land will be likely to run something like this:

First year's expenses on an 80-acre irrigated farm.

First payment on land and water right (one-fifth of $1,600)	$320
Fencing materials	150
Buildings	300
Team, wagon, implements, etc	300
Annual assessment for ditch maintenance	80
Total cash outlay	1,150

To this must be added a year's living expenses. The above items will of course vary with the tastes and means of the settler, but they can not well be greatly reduced below these figures. Of course he may bring his team and implements with him from the East, thus cutting out those items. If he commences in the early fall he may be able, under ordinary circumstances, to do the necessary fencing, clearing, plowing, leveling, and ditching, so as to get 40 acres into crop the following spring. He can hardly hope to do better than that, and may have to have a little help with some of the work. Where this work is done by hired labor, its cost will usually be between $5 and $10 per acre so prepared for crop, depending very largely upon the amount of clearing and leveling required. It is always poor economy to slight this part of the work. Ground should not be put in crop without painstaking preparation for its easy and complete irrigation.

If the farmer under consideration has a sufficient water supply and has fairly good luck with his 40-acre crop, its proceeds will pay his maintenance, assessment, taxes, and, as he has no further payment to make on his land the first year, keep him going for the succeeding year, when he will have his entire 80 acres in crop, and, with the aid of his year's experience, should have a full yield. With careful economy and hard work he will be able to meet his second and succeeding payments on his land from the proceeds of its cultivation, and at the end of five or six years, from an investment of from $1,000 to $1,500, he will become the owner of an 80-acre farm worth probably $50 an acre, and capable of making him a good living, besides, if in a favorable location, constantly increasing in value. This is the result under favorable conditions. If, however, he has been so unfortunate as to locate on poor soil (which is not likely to happen), or under a canal having an uncertain water supply, his case may be decidedly different. His best efforts will avail him nothing if he is not able to get the necessary water at the times needed. This is the most important, as it is sometimes the most perplexing, question to be settled before purchasing. The soil is almost certain to be of excellent quality, and there are few irrigated regions where there is not now a market for all products raised. Prices vary considerably in different localities, owing to local conditions which are largely temporary in their nature. The safest *basis for estimating* prices, however, is not upon such conditions, but,

especially for such products as hay, etc., upon their feeding value upon the farm. Farming throughout the arid region, except as regards such specialized products as fruit, hops, sugar beets, etc., is each year getting nearer that character which long experience has demonstrated as most generally successful and profitable, viz, that in which the bulk of the product is fed on the farm. Success in this kind of farming in the arid States does not necessarily depend upon nearness to railroads or large towns, but is quite largely influenced by other considerations, such as proximity to free grazing lands. Of course favored localities will demonstrate the great success of particular kinds of products, but still the great proportion of farming throughout this region will be of the diversified and general nature practiced elsewhere, and its success will be most largely dependent upon a good water supply. Much farming is done in the arid region under conditions of water supply which are not entirely satisfactory, but its success in all cases is directly proportional to the sufficiency and certainty of the supply. Entire success is only achieved when the water is sufficient in quantity and certain in its duration throughout the period when it is required. Where these conditions prevail the factor of uncertainty is as nearly eliminated from farming operations as can be predicated of any business, and its results are more certain and satisfactory than can be realized from farming in any part of the humid region.

The farmer in the humid States is always practically "between two fires." He may be either burned out by drought or seriously damaged by too much rainfall, and he is powerless to avert either of these evils. The ranchman in the arid region, who is operating under favorable conditions, is protected from the latter by the aridity of his climate, and from the former by his artificial water supply, whose assistance he can invoke at pleasure. He has the exact amount of moisture which he needs, just when he wants it, and at no other time. His operations are rarely delayed by weather conditions. He may plow when the crop needs it, nor is he hampered by either dry or wet weather. If his land is too dry to plow when the crop requires cultivation, he irrigates it to the proper degree of moisture. In most localities he will be able, so far as climatic conditions are concerned, to work on his farm nearly every day in the year. Under favorable conditions he is certain of a large crop, and will be able to harvest it in good condition. Taken altogether, the practice of irrigation furnishes the very ideal conditions for the conduct of agricultural operations.

APPENDIX.

METHODS OF ADMINISTRATION IN THE SEVERAL STATES.[1]

We have pointed out the necessity for careful investigation by intending settlers of the conditions of water supply, priority rights, methods of their enforcement, etc. It is the purpose of this chapter to discuss somewhat more in detail the systems of water administration prevailing in the different States, giving the names of the persons at present charged with these important duties.

For the purposes of this discussion the States under consideration may be divided into two general classes, each class having somewhat similar laws and customs in regard to water administration and distribution. In one grouping may be placed Nebraska, Colorado, and Wyoming; in the other, Idaho, Montana, and Utah. In the former three States the distribution of water from the natural streams to the various parties entitled to its use is vested by law in water commissioners appointed by the governor and acting under direction of the State engineer, who is the head of the irrigation department in each of those States. The methods of adjudicating the various rights to water (as a basis for its proper distribution by the water commissioners) are, however, essentially different in Nebraska and Wyoming from those prevailing in Colorado.

In the first-mentioned States, rights to the use of water are determined by a board of control, constituted by law for that purpose. Under the provisions of the law, the adjudication of the rights to the waters of any stream may be inaugurated by this board at its discretion. It is usually done upon petition of some of the water users. All claimants to the water of the stream are properly notified of the intended adjudication of their rights, and must present their respective claims and evidence to the board at the time and place fixed by it for the taking of such evidence, which place is selected with reference to the convenience of the claimants. After considering all the facts, the board makes a decree fixing the priority and value of each right to the waters of the stream under consideration. These decrees are based upon the records and testimony introduced by the claimants, and upon a very careful examination and survey, under the direction of the State engineer, of the stream, of all ditches diverting water therefrom, and of the areas

[1] See also U. S. Dept. Agr., Office of Experiment Stations Bul. 58.

of land upon which the water is used. The results of this survey are tabulated and mapped for the use of the board in its consideration of the case and determine the volume of water decreed to each claimant. The maps and evidence in each case are made public before the decree is finally entered, and a reasonable time is allowed for contesting any of the facts therein contained. These decrees always specify the land upon which the decreed water is to be used. It is forever inseparable from it, and the water right must always go with the title to the land. The actual beneficial use is made the basis for the decree in all cases. These decrees may be appealed from to the proper court within a certain time after being rendered, but so careful is the board in its examination and determination, and so complete the data submitted by the State engineer, that such right of appeal is very rarely taken advantage of and the determination of the board is very seldom reversed.

In Colorado, on the other hand, these decrees of water rights are rendered only by the district courts after trials under the ordinary rules of evidence as to the facts in each particular case. No special regulations exist governing the character, accuracy, and completeness of the evidence which must be submitted, and no provision is made for any examination or survey under authority of the State to obtain the exact facts as a basis for the determination of the volume of each acquired right. The whole matter is settled in a suit between the various claimants and upon whatever evidence may be introduced by them, while the interests of the State, the real owner of the water, are not represented in the case at all. Frequently there is no real contest in the suit, each claimant getting a decree for the full amount claimed by him. The lack of accurate, as well as the presence of inaccurate and untrue testimony, renders the issuance of a fair and just decree in such cases impossible. The necessity for a painstaking survey of the streams, ditches, and land is very apparent, both for the protection of the interests of the State in the water and those of the appropriators.

An investigation of the results of these two systems of water-right adjudication leaves no room for argument as to which is best suited to the accomplishment of the end in view, which is, or should be, the distribution of the water of the streams in such a manner as to secure its greatest possible beneficial use and the best possible protection of the interests of the actual users of it. The advantages of the system adopted in Wyoming and Nebraska are getting to be generally recognized by all parties interested in a just determination of water rights, and the prevention of costly and interminable litigation in regard to them, which is doing so much to retard settlement and irrigation development in some of the States.

The systems of administration and distribution of the water after the decrees fixing the priority and volume of rights are rendered are practically the same in Nebraska, Colorado, and Wyoming. Each State is divided into several water divisions, each as nearly as practicable em-

L. A. Dickson, commissioner, district No. 5 .... Longmont.
Thomas Kneale, commissioner, district No. 6 .... Niwot.
William E. Cole, commissioner, district No. 7 .... Golden.
A. D. Butterfield, commissioner, district No. 8 .... 1082 Broadway, Denver.
C. B. Clark, commissioner, district No. 9 .... Box 605, Denver.
T. B. Pyles, commissioner, district No. 10 .... Colorado Springs.
D. M. Jones, commissioner, district No. 11 .... Buena Vista.
T. H. Newkirk, commissioner, district No. 12 .... Florence.
Louis Mueller, commissioner, district No. 13 .... Silver Cliff.
T. J. Burrows, commissioner, district No. 14 .... Pueblo.
C. E. Emery, commissioner, district No. 15 .... Pueblo.
James K. Dempsey, commissioner, district No. 16 .... Pueblo.
H. W. Forbes, commissioner, district No. 18 .... Gulnare.
Felix Cordova, commissioner, district No. 19 .... Trinidad.
Lou J. Mitchel, commissioner, district No. 20 .... Alamosa.
David Martinez, commissioner, district No. 21 .... Capulin.
John C. Dalton, commissioner, district No. 22 .... Manassa.
E. E. De Coursey, commissioner, district No. 23 .... Alma.
J. C. L. Valdez, commissioner, district No. 24 .... San Luis.
Gus Peterson, commissioner, district No. 25 .... Mirage.
C. A. Potts, commissioner, district No. 26 .... Sagouche.
A. T. Scott, commissioner, district No. 27 .... Del Norte.
T. P. Goodman, commissioner, district No. 28 .... Sargents.
J. S. Hatcher, commissioner, district No. 29 .... Pagosa Springs.
John T. Sleeth, commissioner, district No. 30 .... Durango.
Frank H. Meyer, commissioner, district No. 33 .... Durango.
D. H. Redmon, commissioner, district No. 34 .... Mancos.
Howard W. Hill, commissioner, district No. 36 .... Plains.
Andrew Kalquist, commissioner, district No. 37 .... Gypsum.
George W. Hull, commissioner, district No. 38 .... Basalt.
Frank D. Squires, commissioner, district No. 39 .... Rifle.
M. H. Payne, commissioner, district No. 40 .... Delta.
W. E. Obert, commissioner, district No. 41 .... Delta.
George Hall, commissioner, district No. 42 .... Collbrau.
J. D. Moog, commissioner, district No. 43 .... Meeker.
William Chadwick, commissioner, district No. 45 .... Rifle.
W. D. Beckwith, commissioner, district No. 47 .... Fort Collins.
E. W. Johnson, commissioner, district No. 48 .... Glen Eyre.
Burt Ragan, commissioner, district No. 49 .... Landsman.
C. B. Rundell, commissioner, district No. 52 .... Redcliff.
C. M. Morris, commissioner, district No. 53 .... Eagle.
P. T. Mellon, commissioner, district No. 61 .... Montrose.
J. W. Landrum, commissioner, district No. 64 .... Sterling.
E. J. Picard, commissioner, district No. 65 .... Yuma.
Jesse Tanner, commissioner, district No. 66 .... Springfield.
J. B. Traxler, commissioner, district No. 67 .... Lamar.
P. H. Shue, commissioner, district No. 68 .... Ouray.
Albert E. Arms, commissioner, district No. 69 .... Rico.

IDAHO.

Douglass W. Ross, State engineer .... Boise.

MONTANA.

Arid land grant commission.

T. C. Marshall, chairman .... Helena.
Donald Bradford, vice-chairman and general manager .... Helena.

D. A. Corey, secretary .... Helena.
Joseph K. Toole .... Helena.
C. O. Reed .... Helena.
W. S. Fortiner, chief engineer .... Helena.

NEBRASKA.

Board of irrigation.

W. A. Poynter, governor (ex officio) .... Lincoln.
C. J. Smyth, attorney-general (ex officio) .... Lincoln.
J. V. Wolfe, commissioner public lands and buildings (ex officio) .. Lincoln.
J. M. Wilson, State engineer (ex officio, secretary) .... Lincoln.

Under secretaries.

E. D. Johnson, division No. 1 .... Lexington.
T. J. O'Keefe, division No. 2 .... Hemingford.

Under assistants.

James Dayley, water district No. 1, water division No. 1-A .... Lewellen.
R. H. Willis, water district No. 2, water division No. 1-A .... Camp Clarke.
I. A. Young, water district No. 3, water division No. 1-A .... Gothenburg.
C. J. Osborn, water district No. 1, water division No. 1-E .... Sidney.
Robert Busch, water district No. 1, water division No. 1-B .... Trenton.

UTAH.

Robert C. Gemmel, State engineer .... Salt Lake City.

WYOMING.

Fred Bond, State engineer .... Cheyenne.
A. J. Parshall, assistant engineer .... Cheyenne.

Division superintendents.

W. M. Gilcrest, secretary State board of control, and superintendent, water division No. 1 .... Cheyenne.
F. S. Kellogg, superintendent, water division No. 2 .... Sundance.
B. B. Morton, superintendent, water division No. 3 .... Tensleep.
John Iredale, superintendent, water division No. 4 .... Rock Springs.

Water commissioners—Division No. 1.

W. D. Pease, commissioner, district No. 1 .... Cheyenne.
George W. Snow, commissioner, district No. 2 .... Little Bear.
J. L. Jordan, commissioner, district No. 3 .... Iron Mountain.
Price Jacobs, commissioner, district No. 4 .... Laramie.
C. H. Jones, commissioner, district No. 5 .... Laramie.
William Brauer, commissioner, district No. 6 .... Saratoga.
Horace Nichols, commissioner, district No. 7 .... Collins.
J. M. Calvert, commissioner, district No. 8 .... Dixon.
Daniel Fitgar, commissioner, district No. 10 .... Johnstown.
J. W. Price, commissioner, district No. 11 .... Casper.
W. F. King, commissioner, district No. 12 .... Rockcreek.
Price Martin, commissioner, district No. 13 .... Glendo.
D. A. Wucherer, commissioner, district No. 14 .... Lusk.

Division No. 2.

F. B. Fawcett, commissioner, district No. 1 .... Newcastle.
John Ridley, commissioner, district No. 2 .... Buffalo.

A. C. Warburton, commissioner, district No. 3....................Buffalo.
M. K. Wood, commissioner, district No. 4........................Sheridan.
Thomas T. Howd, commissioner, district No. 5....................Dayton.
Adolphus Yonkel, commissioner, district No. 6...................Slack.

Division No. 3.

A. P. Battrum, commissioner, district No. 1 ....Lander.
L. P. Hudson, commissioner, district No. 2 ....Lander.

Division No. 4.

Charles Rathburn, commissioner, district No. 1 ....Fontenelle.
M. Henderson, commissioner, district No. 2 ....Afton.
John Shirk, commissioner, district No. 3.........................Robertson.

U. S. DEPARTMENT OF AGRICULTURE,

OFFICE OF EXPERIMENT STATIONS,

A. C. TRUE, Director.

USE OF WATER IN IRRIGATION IN WYOMING

AND ITS RELATION TO

THE OWNERSHIP AND DISTRIBUTION OF THE NATURAL SUPPLY.

BY

B. C. BUFFUM, M. S.,

Professor of Agriculture and Horticulture, University of Wyoming, and
Vice-Director of Wyoming Agricultural Experiment Station.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1900.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., February 27, 1900.

SIR: I have the honor to transmit herewith a paper by Prof. B. C. Buffum, of the University of Wyoming, on the use of water in irrigation in Wyoming and its relation to the ownership and distribution of the natural supply, and to recommend its publication as a bulletin of this Office.

This bulletin has been prepared under the supervision of Mr. Elwood Mead, expert in charge of the irrigation investigations of this Office, and supplies information on the subjects treated, with special reference to conditions existing in the State of Wyoming. The Office is now engaged in collecting similar data in a number of other States and Territories, with a view to a more comprehensive presentation of this matter in the future.

Respectfully,

A. C. TRUE,
Director.

Hon. JAMES WILSON,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
IRRIGATION INVESTIGATIONS,
Cheyenne, Wyo., January 3, 1900.

SIR: I have the honor to submit herewith a paper prepared by B. C. Buffum, professor of agriculture and horticulture in the University of Wyoming, on the use of water in irrigation in Wyoming. It describes his studies on this subject during the past nine years and gives his conclusions regarding certain measures and methods needed to secure the largest service from the available supply.

The investigations of Professor Buffum deal with the same problems as the more comprehensive studies of the duty of water made by the Office of Experiment Stations during the irrigation season of 1899. His measurements were all made in Wyoming, while those of the Office embraced fifteen States and Territories. The first shows the variation from year to year in the quantity of water used to grow the same kinds of crops on the same fields; the second will show the influence of soil, climate, and products in widely separated localities.

The tables and diagrams showing the dates when water was used, its volume and the relations of this use to the available supply, are worthy of study both by practical irrigators and those who have to deal with either the making or administration of irrigation laws.

The results of the measurements of water at Wheatland in 1893, given on page 46, show that the eleven crops grown on plowed land did not require irrigation before June, and the use of water ceased with the middle of August; while with ten of these crops the use of water ended in July. Forage crops grown on land not plowed were irrigated both earlier and later; but this extended use was not so much due to the requirements of the crops as to the fact that they were irrigated when water was most available, rather than when it was most needed. The total length of the season for cultivated crops was therefore less than eighty days, and the total use of water for all agricultural purposes less than six months. The table on page 48 gives the dates of irrigation at Laramie, Wyo., in 1898. These measurements embraced an unusually wide range of products, including twenty crops grown on plowed land and two fields of alfalfa. Notwithstanding

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the variety of crops embraced, no water was used anywhere before June, and none on cultivated land after August. Alfalfa was irrigated later, but the use there ended in September. Although this record included about every crop grown in Wyoming outside of native hay, the total length of the irrigation period was less than one hundred days.

The same table gives the dates of irrigation at the Wyoming Experiment Station farm in 1896 and 1897. While these data include a less number of crops than those before referred to, they show in a more striking way the short duration of the period when water is required. In 1896 water was not needed until after the middle of June, and it was last used on August 14, making the total length of the irrigation period less than sixty days. In 1897 irrigation began June 25 and ended August 16, a total of only fifty-three days.

The entire series of measurements reported in this paper show that there is no considerable use of water in Wyoming before June, and that the irrigation season practically ends with August.

In the general average of the Laramie measurements given on page 50, nearly one-half of the water was used in June. Adding the depths of water used on all crops, gives a total of 240 inches, of which 187 inches were used in June and July.

The table of averages for Wheatland, on page 47, shows even more conclusively the brief duration of the irrigation season in Wyoming. Adding the depths of water used on all crops at this place, gives a total of 220 inches; 112 inches of this was the result of irrigation in June and 198 of that in June, July, and August.

Professor Buffum has stated on pages 51-55, his conclusions as to the significance of these facts. They may be summarized as follows:

Irrigation does not begin until the greater part of the water supply has escaped. The snows of the foothills and lower mountains, where most small streams rise, melt before the middle of June, which is about the date when active irrigation begins.

The use of water in irrigation is not continuous. On the contrary, there are six months in which, as a rule, water is not used at all. The practical use occurs between June 15 and August 15, or only two months out of the twelve.

Ignoring this, irrigation laws have followed mining practices where the use of water is continuous, and made rights for irrigation continuous; thus giving to ditch owners the same right for the portion of the year when water is not needed as they have for the period of actual use. This surplus right therefore is not based on any actual necessity.

In order to make the best use of the water, which now runs to waste before irrigation begins, it will have to be stored. A comprehensive system of reservoirs will require public aid, either from the State or

nation, and public supervision in the distribution of the stored water. If this is undertaken, the question will at once arise, Who owns the stored water? If it shall be held that the rights for the nonirrigation period now being acquired are vested and absolute, such rights will absorb the entire volume which can possibly be held in reservoirs. So far as Wyoming is concerned this is as yet a speculative question, but it is certain to become one of great practical importance.

The complications thus indicated by Professor Buffum have been obviated in the irrigated countries of Europe by making a well-defined distinction between rights for water for the irrigation and nonirrigation periods, and between the rights for water used strictly from the streams and rights for stored water. Few, if any, of the older irrigated districts follow our practice of making grants for streams either free or perpetual. On the contrary, the licenses issued are for a specified period and contain specific restrictions both as to the dates when water is to be taken and the purposes for which it is to be used. Without exception the districts in Europe where irrigation is most successful are those in which rights to water for irrigation are attached to the land and are inseparable therefrom. This prevents the complication regarding surplus of speculative rights, and yet at the same time gives to the actual user full protection.

The tables given in this paper show that the practice of basing the dimensions and capacities of canals on an assumed average duty for the entire season will not meet the requirements of irrigation practice in Wyoming, where two-thirds or more of the water is required in a period of sixty days. The experience of irrigators in that State has also shown this to be true. It has generally been found that when the entire area along a canal has been brought under cultivation the dimensions of the canal have been too small.

Respectfully,

ELWOOD MEAD,
Irrigation Expert in Charge.

DR. A. C. TRUE, *Director.*

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THE USE OF WATER IN IRRIGATION IN WYOMING.

INTRODUCTION.

There are some things about irrigation which are fairly well understood. We have learned how to build ditches and operate them in the distribution of water. The simpler laws of plant growth are becoming well understood, and the amount of water taken up by the plant, used in its development, and thrown off by it is being studied. Comparatively little effort has been made to determine how much water must be applied to the land by irrigation to mature the plant and to unravel the somewhat intricate relations between water, soil, climate, and a profitable crop. The knowledge lacking in irrigation and which must in some way be obtained before our water supply will be either wisely or correctly used is how much is required to secure the best results, and when and by what means it can be most economically and efficiently applied. The area of land in arid regions which can be ultimately reclaimed is limited by the water supply. Anything which will extend the use of this supply will add to the ultimate wealth and population of this region, but if, through lack of knowledge of the actual necessities of irrigation, rights to water are acquired which have no relation to these necessities, and these rights become fixed by custom into laws, the train of evils which will follow will seriously restrict the acreage brought under cultivation and add greatly to the cost thereof. The problem is a large one. It will require much repetition of experiments and long and careful study before the question can be fully solved, but the end in view promises returns more than commensurate with the cost.

The settlement of a vast territory, and the ultimate prosperity and happiness of its people, depend upon the artificial application of water to the land. Already the population has increased to such an extent that all the public domain in the humid States and practically all that in the arid regions which can easily be brought under irrigation has been absorbed, so that there is no longer opportunity for the sons of farmers to cultivate free land unless it be at great expense for reclamation. Already the time has arrived when many irrigated districts have so far developed that scarcity of water is keenly felt, and the

good of the community demands that there shall be no unnecessary waste of the limited water supply. Without a knowledge of the amount of water which may be available and of the amount required for the successful production of crops, who shall say whether or not the supply is economically distributed, or whether that used is adequate or inadequate, beneficial or injurious, or to what extent the land not yet irrigated may be made productive? To elucidate such weighty and far-reaching questions as these we must by actual measurements determine how much water may be obtained, how much is applied to the land and crop, how much is lost in various ways (in order to bring into practice means of preventing such losses, so far as possible and practicable), and how much is required by different crops on different soils in different climates and different seasons. By careful, persistent, and intelligent study of these factors, along with the resulting crop production, we may finally arrive at more or less definite conclusions in regard to the possibilities and limitations in our future agricultural development.

Under the best irrigation laws now in force the water belongs to the State, and the amount which the individual may appropriate for his land is not more than he is able to prove is applied to beneficial use.[1] Such laws open the way to the greatest possible development of our natural agricultural resources. The limit of that development will be known only when we know the amount of the supply and are informed in regard to what constitutes beneficial use.

The fundamental principles of the application of water to crops have been the last to receive attention. Although irrigation is almost as old as agriculture, the average irrigator readily acknowledges his ignorance of the amount of water necessary to produce a maximum crop, and his idea of the amount of water actually applied to his land year after year is about as vague and indefinite as his knowledge of the distance to the nearest star. At the same time intelligent users of water are fast waking up to the fact that this kind of information is of vast importance. Without a knowledge of the amount of water required by the land and crop no just and equitable distribution of water among appropriators can be made. Without it there is constant danger of litigation over the right to use water. Without it the determination of the man with the prior right to get his share, or all the law has given him, results in his injuring his crops by overirrigation, while his neighbor who has appropriated at a later date sees his crop destroyed by drought. Without it courts have decreed enough water

[1] This is in accord with the rulings of the Wyoming State board of control, and has hitherto governed the division of streams among appropriators. Since the paper was written this doctrine has been set aside by a district court decision, which holds that water rights are personal property and that parties can appropriate more than they need and sell the surplus.

to one man to cover his land over 500 feet deep and to another less than enough to cover it 1 foot deep.[1]

In the arid regions values attach to the water rather than to the land. Water is scarce, while land is comparatively abundant. There is approximately ten times as much land as the water supply under present usage will irrigate. The increase in value of land as soon as it is reclaimed and is insured a permanent water supply is enormous. Professor Carpenter, writing for Colorado, states that "a doubling of the duty would increase the public wealth of the State from this source alone by $20,000,000." Undoubtedly the efficiency of our water supply can be improved to a great extent when the relation of water to the soil and crop becomes properly understood—when the land has been cultivated and irrigated a number of years, and a better agricultural practice becomes general.

A knowledge of the amount of water necessary to reclaim land and produce profitable crops of the kinds which succeed under existing conditions of soil and climate is clearly a matter of first importance to the appropriator, that he may obtain enough for that purpose; to the State land boards and to the courts, that just and equitable settlement may be made of all questions relative to the use of water; and to the Commonwealth, that the greatest amount of land may become profitable and support a maximum population. Without such information legislators have adopted and reenacted land laws from other places which do not fit the conditions under irrigation at all, and too often the irrigation laws which have been put in force have been unjust and inadequate. A vast system of agriculture under irrigation has grown up in arid America, upon which thousands of families are dependent for a livelihood, and the irrigation codes have been framed for their benefit and protection, with only a limited knowledge of the water supply and the duty of water. Clearly, those laws have been most efficient and just which in some way recognize water duty, as in Wyoming and Nebraska, where they provide that the water attaches to the land irrigated by it, and the amount of appropriations are limited to the volume actually applied to beneficial use. The framers of the Wyoming irrigation laws, with great wisdom, foresaw the value of such recognition, and are to be congratulated upon establishing a code under which very little litigation has sprung up. Much trouble has been experienced in the States where companies, under the name of "common carriers," or individuals, have been given control of large amounts of water, to be used by them as an article of trade to be sold to this or that farmer who will pay most for it. When water has been diverted under individual ownership and becomes a source of speculation, and court decrees have given water in excess of the natural supply, or have provided one man with more than he can use and another with not enough

[1] *U. S. Dept. Agr.*, Office of Experiment Stations Bul. 58.

to carry on profitable farming, what wonder that litigation has caused expenditures of millions of dollars, or that unhappy feuds between unhappy farmers have sprung up and the irrigating shovel has become a weapon of offense and defense?

The investigations which have been carried out demonstrate that duty in any locality varies between somewhat wide limits, so that distinctions can not be too closely drawn. The limit of an appropriation should be no less than the maximum amount needed in ordinary practice. One cubic foot per second for 70 acres, as given in Wyoming, has proved sufficient under ordinary conditions, even for newly irrigated land and for native hay, which require more water than old land or other crops. More measurements of the amounts actually used on farms are needed before a close estimate can be made of what may be accomplished with the available supply.

The larger part of the material used in the preparation of this report has not heretofore been published, and has been obtained through water measurements and investigations by the Wyoming Experiment Station in cooperation with the Office of Experiment Stations of the United States Department of Agriculture. To this have been added some measurements made by the Territorial engineer of Wyoming, at Wheatland, Wyo., where the station afterwards made a series of determinations of the duty of water. It has been thought best to avoid using compilations from other sources.

APPLICATION OF WATER TO CROPS.

Every agriculturist realizes that more or less water is necessary to the growth of plants, that the larger part of the substance in the growing plant is water, and that his crops promptly dry up and die when the supply of water in the soil is exhausted. We know that water is taken up from the soil by roots, that it aids in the assimilation of food by the plant, and is lost into the air by transpiration. The nature of these processes in the plant is not related to this discussion, but the amount of water so used is of first importance.

QUANTITY OF WATER REQUIRED BY CROPS.

Some investigations of the amount of water actually needed by the plant have been made. While they are not wholly applicable to plants raised in an arid climate, they are of interest. Professor King, of the Wisconsin Experiment Station, found that the average amount of water required to produce one pound of dry matter was, in round numbers, 393 pounds with barley, 506 pounds with oats, 453 pounds with clover, 310 pounds with corn, 477 pounds with field peas, and 423 pounds with potatoes.[1] With the yields he obtained this amounts to a depth of 1.5

[1] Wisconsin Sta. Rpt. 1894, p. 248.

feet used by the crop of barley, nearly 1.6 feet by the oats, a little over 1.6 feet by the clover, and over 2 feet by corn, peas, and potatoes. According to the plan of these experiments, no account was taken of the loss of water by evaporation from the soil. These amounts are the total quantities of water received by the soil in which the crop grew and used by the plant, evaporated from the soil surface or lost by drainage, there being no other source of loss. The application of water to the plants approached the manner of supplying water in the arid region. When too much water fell as rain, it was kept away from the crops by shelter, and when the plants needed water it was supplied artificially. In every case there was increased crop when water was artificially applied, a strong argument in favor of irrigation for the humid region. In experiments of the Wyoming Station the same facts were not taken account of as in those recorded by King, but it is of interest to note the amount of water supplied to crops by irrigation and rainfall during the growing season.

Barley, which produced profitable crops, received at different times and places in our experiments from 12.8 to 37 inches of water; oats received from 20.6 to 48.8 inches of water; corn received 14.8 inches of water. This is merely a statement of the depth of water applied to the crops, and takes no account of the water lost by waste from the surface or by seepage below. Leaving out of account the unknown variations in soils and climatic conditions, it would not appear from these figures that excessive amounts of water were used in irrigation.

The following table shows the quantity of water used for a given quantity of crop harvested:

Water applied and the crop produced.

Crop.	Place.	Year	Water received by irrigation, per acre.		Depth of water over surface	Yield per acre.	Water used per pound of crop produced
			Cu. ft.	*Pounds.*	*Feet.*	*Pounds.*	*Pounds.*
Alfalfa, 3 crops	Wheatland	1893	113,184	7,071,000	2.60	15,752	448.9
Alfalfa, 2 crops	Laramie	1896	47,356	2,959,750	1.09	4,664	634.6
Alfalfa, first year, 1 crop	do	1898	129,388	8,086,750	2.97	2,220	3,642.7
Alfalfa, 2 crops	do	1898	113,101	7,068,813	2.60	8,668	815.5
Barley, 3 varieties	Wheatland	1893	39,744	2,484,000	.92	1,008	2,464.3
Barley, 9 varieties	Laramie	1896	52,895	3,365,937	1.21	896	3,756.7
Barley, subsoiled	do	1896	63,296	3,958,000	1.45	1,325	2,987.2
Barley, not subsoiled	do	1896	68,296	3,958,000	1.45	1,292	3,063.5
Barley	do	1897	69,345	4,334,062	1.59	1,927	2,249.1
Barley, Highland Chief	do	1898	117,711	7,356,937	2.70	1,892	5,285.2
Barley, Highland Chief, subsoiled, straw and grain	do	1898	75,159	4,697,337	1.73	2,168	2,166.7
Barley, Highland Chief, subsoiled, grain.	do	1898	75,159	4,697,337	1.73	527	8,913.4
Barley, Highland Chief not subsoiled, straw and grain.	do	1898	75,159	4,697,337	1.73	2,273	2,066.6
Barley, Highland Chief, not subsoiled, grain.	do	1898	75,159	4,697,337	1.73	751	6,254.8
Corn, Minnesota King	Wheatland	1893	47,520	2,970,000	1.09	2,414	1,230.3
Flax	Laramie	1897	69,345	4,334,062	1.59	2,104	2,059.9
Flax, Belgian	Wheatland	1893	95,040	5,940,000	2.18	504	11,785.7
Flax, White Russian	do	1893	95,040	5,940,000	2.18	480	12,375.0
Oats, 3 varieties, average	Laramie	1898	53,981	3,373,812	1.24	1,555	2,169.7
Oats	do	1897	69,345	4,334,062	1.59	1,162	3,729.8
Oats, Bonanza	do	1898	82,647	5,165,[illegible]	1.90	2,455	2,[illegible]

Water applied and the crop produced—**Continued.**

Crop.	Place.	Year.	Water received by irrigation, per acre.		Depth of water over surface.	Yield per acre.	Water used per pound of crop produced.
			Cu. ft.	*Pounds.*	*Feet.*	*Pounds.*	*Pounds.*
Oats, Early Archangel	Wheatland	1893	68,256	4,256,000	1.57	1,024	4,156.3
Oats, Giant Side	do	1893	76,896	4,806,000	1.77	1,603	2,998.1
Oats, Lincoln, cultivated	Laramie	1897	107,012	6,688,250	2.46	1,662	4,024.2
Do	do	1898	75,853	4,740,812	1.74	992	4,779.0
Oats, Lincoln, field culture	do	1897	107,012	6,688,250	2.46	1,456	4,593.6
Do	do	1898	75,853	4,740,812	1.74	530	8,944.9
Oats, Lincoln, on sod	do	1898	112,579	7,041,181	2.58	698	10,087.7
Oats, not subsoiled	do	1896	63,296	3,958,000	1.46	1,345	2,942.8
Oats on sod	do	1896	41,886	2,617,875	.96	542	4,830.0
Oats subsoiled	do	1896	63,296	3,958,000	1.46	1,520	2,603.9
Oats, surprise	do	1898	82,647	5,165,237	1.90	2,150	2,402.4
Oats, Surprise, not subsoiled, grain.	do	1898	75,159	4,697,337	1.73	1,576	2,980.5
Oats, Surprise, not subsoiled, grain and straw.	do	1898	75,159	4,697,337	1.73	4,445	1,056.8
Oats, Surprise, subsoiled, grain.	do	1898	160,835	10,052,187	3.69	1,634	6,151.9
Oats, Surprise, subsoiled, grain and straw.	do	1898	160,835	10,052,187	3.69	5,484	1,833.0
Oats, Surprise, subsoiled, grain.	do	1898	75,159	4,697,337	1.73	1,303	3,607.8
Oats, Surprise, subsoiled, grain and straw.	do	1898	75,159	4,697,337	1.73	3,645	1,288.7
Oats and vetch for hay, cured hay.	do	1898	68,753	4,295,062	1.58	5,563	772.1
Peas, straw and grain	do	1897	74,699	4,668,687	1.71	3,232	1,444.5
Peas	do	1898	124,309	7,769,312	2.85	828	9,383.2
Potatoes, 22 varieties	Wheatland	1893	61,776	3,861,000	1.42	7,344	525.7
Potatoes	Laramie	1895	11,683	730,186	.27	9,000	81.1
Potatoes, not subsoiled, irrigated 3 times	do	1898	49,825	3,114,062	1.14	8,759	355.5
Potatoes, not subsoiled, irrigated twice.	do	1898	12,925	807,812	.30	4,972	162.5
Potatoes, subsoiled, irrigated 3 times.	do	1898	49,825	3,114,062	1.14	8,591	362.5
Potatoes, subsoiled, irrigated twice.	do	1898	12,925	807,812	.30	5,290	152.7
Rye	do	1897	69,345	4,334,062	1.59	1,518	2,855.1
Rye, spring	Wheatland	1893	56,160	3,510,000	1.29	974	3,603.7
Rye, winter	do	1893	38,448	2,403,000	.88	739	3,251.7
Sugar beets, 4 varieties	do	1893	107,128	6,695,500	2.46	12,912	518.5
Sugar beets and ruta-bagas	Laramie	1898	69,875	4,367,187	1.60	5,622	776.8
Timothy	Wheatland	1893	102,584	6,410,000	2.35	2,212	2,897.8
Turnips and ruta-bagas	Laramie	1895	112,765	7,047,812	2.59	18,000	391.5
Wheat, 18 varieties, average	do	1896	53,981	3,373,812	1.24	1,868	1,806.1
Wheat, 5 varieties, average	do	1898	156,401	9,775,062	3.63	1,573	6,214.3
Wheat, Blount No. 16, cultivated.	do	1897	107,012	6,688,250	2.46	630	10,616.3
Do	do	1898	75,853	4,740,812	1.74	841	5,637.1
Wheat, Blount No. 16, field culture.	do	1897	107,012	6,688,250	2.46	965	6,930.8
Do	do	1898	75,853	4,740,812	1.74	930	5,097.6
Wheat, not subsoiled	do	1896	63,296	3,958,000	1.46	997	3,969.9
Wheat, on sod land	do	1896	41,886	2,617,875	.96	428	6,116.5
Wheat, Scotch of Scotch, not subsoiled, grain.	do	1898	75,159	4,697,337	1.73	833	5,639.1
Wheat, Scotch of Scotch, not subsoiled, straw and grain.	do	1898	75,159	4,697,337	1.73	2,127	2,208.4
Wheat, Scotch of Scotch, subsoiled, grain.	do	1898	75,159	4,697,337	1.73	527	8,913.4
Wheat, Scotch of Scotch, subsoiled, straw and grain.	do	1898	75,159	4,697,337	1.73	2,170	2,164.7
Wheat, subsoiled	do	1896	63,296	3,958,000	1.46	943	4,197.2
Wheat, White Russian	Wheatland	1893	69,984	4,374,000	1.61	1,962	2,229.4
Wheat, winter, Fultz	do	1893	41,040	2,565,000	.94	486	5,277.8

The weight of crop harvested is subject to much variation. In some instances it will be noted that only the number of pounds of grain produced is given, while in others the grain and straw were weighed but no account was taken of the stubble which was left in the field. The amount of crop here given does not represent the dry matter, so the results in this table are in no way comparable with those given by

King, cited above. The amount of water per pound of crop varies with all the conditions affecting the duty of water, and with all the conditions affecting the yield of crop as well. It simply shows the amount of water used and the yield obtained as the crops are usually taken from the field by the farmer. With large yields from sod land, which requires a large amount of water, the number of pounds of water applied for each pound of grain harvested is very large, being about ten thousand to one in some instances; while with potatoes, which produce large crops with little irrigation, the amount of water is as little as 81.1 pounds for each pound of crop. The average of four measurements of alfalfa shows 1,385.2 pounds of water for each pound of cured hay; eight measurements of barley show 3,659.8 pounds of water for each pound of threshed grain; eighteen measurements of oats give 4,107.4 pounds of water for each pound of grain; six measurements of potatoes give 273.3 pounds of water for each pound of marketable potatoes; and fourteen measurements of wheat average 4,854.3 pounds of water for each pound of grain.

It will be observed that there is a limit to the volume of water which can be used to advantage, beyond which it is an injury to both land and crop. With alfalfa the largest yield was obtained with the least water per pound produced, and the same is true in several cases with the grains and potatoes. However, it will be found in the results recorded in the table that in general the greatest depth of water applied to the crop in irrigation nearly corresponds to the maximum yield, except in the case of grains on sod land, or potatoes, which received little irrigation.

It will thus be seen that we are unacquainted as yet with the amount of water necessary to produce the best results under any known conditions. With too little water, failure of the crop is certain, and too much water is often injurious. So far, we have been able to obtain only a general idea of the amount of water necessary to carry on successful agricultural operations and produce crops which give larger average yields than those raised under rainfall. Undoubtedly, applying water to the plant when it needs water and not forçing it to exist in the presence of water in excess of that required is the only scientific way of producing crops.

WHEN TO IRRIGATE.

The question of when to irrigate is so closely related to the water supply and its consumption that it merits careful consideration. The time to irrigate depends largely on the crop, the weather conditions, and the soil. Over a large part of Wyoming, where meadows are irrigated for the production of hay, it is the common practice to turn the water on the land just as early in the spring as it can be run

through the ditches. Ordinarily the water is placed on the meadows about the middle of April and runs continuously until about the middle of July, being turned off only long enough before mowing to allow the land to dry out so the water will not interfere with the work of haymaking. This time varies in different places from one day to two weeks before mowing begins. One farmer has stated that he turns the water off his meadows the day he begins to cut the grass, and depends upon the land drying rapidly enough so the moisture will not interfere with curing the hay; and another explained that he had obtained a mowing machine which would cut right along under 6 inches of water.

Various reasons are given for turning the water on the meadows as early as possible. A ranchman, who raises excellent crops of hay on the Laramie plains, states that the water draws the frost out of the soil, softening the land so the grass can make an early start and produce larger growth than where naturally held back by the cold weather. Another ranchman near Laramie says: "Where the soil is covered with alkali (and practically all the land here is alkali land) the white incrustations of salts interfere with the growth of grass and keep the land cold by reflecting the sun's rays. If the water can be run over the land enough to wash off the alkali, or dissolve it and carry it into the soil, the grass thickens up and makes a good crop." Whatever the reason, it is evident that the ranchmen of Wyoming, as a rule, believe in irrigating native hay land as early and as long as possible, and all use the most water when the largest amounts can be obtained from our streams, which is during May and June.

The time to irrigate cultivated crops can not be definitely stated. Absolutely no working rule has been discovered. Up to the present time farmers have generally applied water through judgment born of long experience, rather than through an intelligent conception of the needs of the plant. Often the one who irrigates can not explain clearly how he knows his crop is in need of water. To the uninitiated the crop may be apparently thriving and the need of water seemingly remote, when the farmer turns on a head of water and does not rest day or night till all his land has been watered. Evidence of his correct judgment is forthcoming in the large yields which fill his granaries and root cellars. Some say that plants do not need irrigating until they show signs of wilting, but for most plants this would be waiting too long. The crop would never fully recover its strength and vigor. This rule may be applied to corn, however, which is ordinarily said not to be suffering so long as the wilted leaves straighten out at night. Some farmers will inform you that they discover when water is needed by the color of the plant; but this is not an altogether safe guide, for color is influenced by so many other conditions that it *can not be* relied upon as an index to the need of water. More intel-

ligent farmers will probably explain that they have examined their soil and know from experience that when it reaches a certain condition of dryness their crops will soon suffer unless water is supplied. Dr. Hilgard, of the California Experiment Station, states that this questioning of the soil is the only accurate way to tell when irrigating should be done. The percentage of moisture in the soil in which plants of different kinds flourish best is not known, and much experimenting will be necessary before definite rules based on this factor can be formulated. That there are periods in the life of the crop when irrigation will be especially effective can not be doubted, and it is equally true that irrigating at the wrong time may do more harm than good. The opinions of neighboring farmers in regard to the proper time may vary widely, and the one who makes the closer guess reaps the larger crop. To illustrate—in 1898 a question arose in regard to when potatoes should be given the first irrigation. The opinion of old irrigators differed so widely that it was decided to put the matter to the test. A part of the potato field was given the first irrigation July 7, while a part was left until July 28 for the first watering, at which time the potatoes irrigated on July 7 were given their second irrigation, and all were irrigated again on August 4. The potatoes were planted in rows running across two plats, one of which was plowed in the ordinary way. The other plat was treated the same, but had been subsoiled in the spring of 1896 to a depth of 16 or 18 inches. The potatoes irrigated twice received 3.6 inches of water, while those irrigated three times received 13.8 inches. The yields of marketable potatoes per acre are given in the following table:

Yield of potatoes with two and three irrigations.

Irrigations.	Land plowed.	Land plowed and subsoiled.	Average yield.
	Pounds.	*Pounds.*	*Pounds.*
Irrigated twice	4,972	5,290	5,131
Irrigated three times	8,759	8,591	8,675
Increase	3,787	3,301	3,544

This table shows an increased yield due to the additional irrigation of over 76 per cent on land treated in the usual way, and of nearly 62.4 per cent on subsoiled land, the average increase being over 69 per cent. This shows that with potatoes, at least, irrigation should not be put off until the crop begins to burn, as is often done with grain. Many withhold water from their potatoes until the young tubers are set, in order not to stimulate the vines into forming more tubers than will grow to good marketable size, while others try to irrigate before or at the time of setting the tubers. No experiments are at hand to show which of these two methods is preferable,

There is much difference in the number of irrigations given the same kind of crop in different places. Reference to the tables and charts (pp. 46 ff.) giving the distribution of irrigation water through the season shows that five or six irrigations are not uncommon at Wheatland, while rarely more than three are given at Laramie. Some soils absorb less water and retain it less tenaciously than others. Because a crop in one place needs irrigating is no reason a like crop in another location needs water at the same time.

FALL AND WINTER IRRIGATION.

The soil itself may be used as a storage reservoir. The possibility of storing water in the soil is becoming better understood and the practice is rapidly becoming more general. In parts of Kansas it has been found possible to store enough water in the soil by winter irrigation to mature the summer's crops. There are large ranches in Wyoming with a limited supply of water on which the irrigation water is systematically spread over the hay land in the winter to supply moisture to the coming crop. Such practice enables the owner to double the amount of meadow from which he can put up hay, as the land supplied with moisture in the winter is not irrigated during the summer months and the summer supply is used on separate areas.

The value of conserving the moisture on fruit lands by mulches through the winter has long been understood and is widely practiced, and the value of winter irrigation for orchards is no longer questioned. In the arid region the winters are long and dry, there is no continuous mulch of snow, and the orchardist who can not irrigate late in the fall or occasionally through the winter is unfortunate.

The value of irrigating alfalfa in the fall has been tested by the Wyoming Experiment Station. Alfalfa irrigated late in the season, October 2 and 3, 1895, did not winterkill as badly as that not irrigated. The quantity applied can not be stated accurately, but as nearly as can be estimated enough was used to cover the land 6 inches deep. The plants which were fall irrigated started earlier in the spring and made better growth, at one time being 4 to 5 inches higher than those not so irrigated, and the dividing line marked by the water could be traced up to the time of the first cutting in 1896. In spite of the fact that evaporation was sufficient to remove nearly or quite all of this water during the winter months, its influence was felt far into the next growing season.

On land which is used for the production of cultivated crops, where the surface soil can be stirred frequently to prevent the loss of water by evaporation, winter irrigation is far more effective than on grass land. In parts of California, water supplied the land during the winter or wet season is often sufficient to mature crops, though they may not *receive any* water between planting and harvesting. In such places

complete and continuous cultivation is practiced to prevent the soil from losing its store of moisture through evaporation. Where water is stored in this way for the coming crop it is necessary to conserve the moisture by continually stirring the surface to form a natural mulch which will prevent evaporation.

WATER MEASUREMENTS IN WYOMING.

CONDITIONS UNDER WHICH THE MEASUREMENTS WERE MADE.

Historical and general.—A brief account of the conditions under which the water measurements reported in the following pages were made is thought advisable, as it will help the reader to a better understanding of them. Without some information of the locality in which measurements are made, the general conditions of the soil and climate, and the methods and instruments used, a clear idea could not be obtained of the manner in which the final results were reached.[1]

Measurements of the water used on the station farm have been made at Laramie since the spring of 1891, and a series of measurements were made at the substation at Wheatland in 1891 and 1893. Some measurements to determine the duty of water were made at Wheatland in 1889, under the direction of the Territorial engineer, Elwood Mead, and as they are closely related to the subsequent measurements made by the station at that place the results are used in this report.[2]

The irrigation experiments at the station have been carefully made. The water has been economically used; the irrigator has always prevented the water from going to waste, so far as possible, and confined the measurement to the special plat under investigation, in order to determine duties for each crop separately. It was thought that a series of measurements of the water actually used by farmers in their ordinary practice would be of value for comparison. In fact, it was believed that the making of such measurements was the only way to find out how the water supply is actually being used, and such information is necessary before we can point out where change in present irrigation practice is feasible or desirable. To gather this kind of information, a measuring weir and register were placed in 1898 on a farm situated on the open plains, 16 miles from Laramie, under the Pioneer Canal. The soil is a loose gravel extending to a depth of about 10 feet, and on account of the natural drainage requires large

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[1] It has been the privilege of the writer to plan and carry out the irrigation investigations at the Wyoming Experiment Station since it was established in 1891. The farm was then platted and ditches so constructed that all the water used in irrigating could be accurately measured.

[2] The duties determined at Wheatland in 1891 and at Laramie in 1891 and 1892 were reported in Bulletin 8 of the Wyoming Experiment Station. These results are also reported in this bulletin, but with the above exceptions none of the measurements used in the preparation of this report have been heretofore published.

amounts of water. The owner of the farm used the water exactly as he would otherwise have done, and we secured trustworthy measurements of the water so used.

The experiment farm is situated 2 miles west of Laramie, under the Pioneer Canal. The land slopes toward the east, with a grade of from 3 inches to 1 foot to 100 feet, but the soil does not wash badly even where the slope is greatest. The soil is a sandy loam from 15 or 18 inches to over 5 feet deep, and the greater part of the farm is underlaid with gypsum and carbonate of line, and with sandstone. The soil is sticky when wet and of such consistency that it is difficult to make a plow scour in it at any time unless it is very dry. The soil absorbs water readily, and seems to retain the moisure better than most open and loose soils in this region. The altitude of the station farm is about 7,200 feet; it is situated on the open plains without protection of any kind, and the drying winds of winter and spring leave the soil with little moisture unless it is irrigated.

The growing season is comparatively short; usually frost is out of the ground so plowing can be done by April 10. Spring frosts of greater or less severity may be expected up to June 1, and a light early frost about August 20, though killing frosts may hold off until September 10 or 20. On account of the short season, only those crops can be successfully raised which can stand a few degrees of frost after the seed is sown in the spring.

The farm upon which measurements were made at Wheatland is at an altitude of about 4,700 feet; the soil is much like that at Laramie, though it is deeper and probably contains smaller amounts of gypsum and alkali salts. The land has a gentle slope, which makes it irrigate well. It is on the open plains with no protection from the winds, but the season is long and killing frosts often hold off in the fall until as late as the middle of October.

The methods of applying water used have been flooding and furrow irrigation. As a rule grains and grasses are irrigated by flooding, and potatoes and other root and garden crops by the furrow method. In some of our experiments grains were raised in rows, planted twice as far apart as the ordinary drill row. These grains have been irrigated in small furrows between the rows and otherwise cultivated as hoed crops. An expert irrigator will handle a large head of water with either of these methods, without allowing appreciable waste.

A second weir was placed on the lowest point of the farm at Laramie to measure the waste water, but so little escaped that the flow over a 1-foot weir was too small to be accurately determined, and such measurements were discontinued.

Precipitation and evaporation.—The precipitation and evaporation of the region in which the measurements were made as observed at Laramie since 1891 are shown in the following table:

Precipitation and evaporation, Laramie, Wyo.

Month.	1891.		1892.		1893.		1894.	
	Rainfall.	Evaporation.	Rainfall.	Evaporation.	Rainfall.	Evaporation.	Rainfall.	Evaporation.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
January	0.70	....	0.01	....	Trace.	....	0.03	....
February	.375	....	.36	....	0.11	....	.10	....
March	1.50	....	.52	....	.29	(*a*)	.29	....
April	.25	....	.19	(*b*)	.32	*c* 0.562	1.51	*d* 0.906
May	2.92	....	1.16	*e* 1.59	.33	4.801	.42	6.06
June	.91	....	3.97	8.23	.54	7.884	.64	7.492
July	1.20	*f* 4.421	2.22	9.19	.34	9.352	1.41	6.69
August	1.76	8.59	.14	8.27	1.08	6.586	1.26	6.276
September	1.80	5.04	Trace.	6.10	.39	6.016	1.60	6.436
October	.30	3.72	3.96	*g* 1.50	.28	2.886	.09	3.306
November	1.095	*h* .926	Trace.	....	.06	....	.05	....
December	1.11	....	.20	....	.10	....	.23	....
Total	13.92	22.70	12.73	34.88	3.84	38.087	7.63	37.166
Total precipitation for May, June, July, and August	6.79	....	7.49	....	2.29	....	3.73	....

Month.	1895.		1896.		1897.		1898.	
	Rainfall.	Evaporation.	Rainfall.	Evaporation.	Rainfall.	Evaporation.	Rainfall.	Evaporation.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
January	0.08	....	0.44	....	0.39	....	0.05	....
February	.14	....	.17	....	.16	....	.01	....
March	.43	....	.59	....	3.97	....	.40	....
April	.87	*i* 2.58	3.53	....	.56	*c* 1.80	1.26	*j* 3.44
May	2.09	7.334	.48	....	1.85	7.43	1.88	4.60
June	2.12	6.236	1.72	7.79	.72	7.73	.90	*k* 10.33
July	2.71	7.294	1.66	8.34	1.29	7.00	.65	8.37
August	1.17	6.066	.89	6.09	1.11	7.33	1.16	6.93
September	.18	4.944	1.16	4.84	.32	4.84	Trace.	5.68
October	.74	2.616	.18	*l* 2.00	.55	*m* 4.38	.48	*n* 2.05
November	.32	....	.09	....	.33	....	.61	....
December	.33	....	.00	....	.75	....	.23	....
Total	11.18	37.02	10.91	29.06	11.99	40.51	7.63	41.40
Total precipitation for May, June, July, and August	8.09	....	4.75	....	4.97	....	4.59	....

a From October 1, 1892, to October 1, 1893, evaporation was, apparently, 46.305.
b Evaporation between November 11, 1891, and May 24, 1892, was 9.69 inches. Liable to considerable error.

c 24th to 30th.
d 26th to 30th.
e 24th to 31st.
f 22d to 31st.
g 1st to 10th.
h 1st to 11th.
i 17th to 30th.
j 15th to 30th.
k An exceptionally dry and windy month.
l 1st to 22d.
m 1st to 26th.
n 1st to 15th.

Although the rainfall is small (averaging 9.95 inches for the eight years) its distribution through the year is most favorable for crops. The month of heaviest rainfall is usually May or June, and enough is generally obtained early in the season to insure germination, so the crop can begin its growth without being irrigated. There are serious objections to irrigating after the seed has been sown, to bring the

plants up, as the crop rarely fully recovers. Where the soil is too dry to insure proper germination it should be irrigated before plowing or at least before planting. In the table the annual precipitation and the amount for four months—May, June, July, and August, the arbitrary irrigating season here adopted—are given; a mean of 5.33 inches has fallen during these months, which is very nearly 54 per cent of the annual precipitation. The average here given for eight years is probably below the normal for Laramie, as that of 1893 was unusually small, not only at Laramie, but over the whole eastern part of the State. It may be remarked here that water failed in the Pioneer Canal early in that season, and the rainfall, being so small, was insufficient to carry the plants through, so general failure of crops on the experiment farm resulted in 1893. As already stated, the growing season at the high altitude of Laramie is comparatively short, and any cause which delays the time of maturity, even a few days, may be fatal. A heavy rain when the crop first requires water may preclude the necessity of irrigating for one or two weeks, and its effect upon the amount of irrigation water needed to mature the crop is apparent. Without considering the rainfall in each case, a clear understanding could not be obtained of the duties of water reported, so great care has been taken to accurately report precipitation in connection with the tables of duties.

The evaporation is heavy over the larger part of the arid region, and while we have not been able to measure the evaporation accurately for the entire year, it has been carefully observed for the season when the water was not frozen. The measurements of evaporation were made from a galvanized iron tank of 1 cubic meter capacity set into the ground even with the surface. The water was accurately measured each day by means of a hook gauge, and the tank was filled from time to time to keep the water near the top so that evaporation would not be influenced by reflections of heat from the sides of the tank.

Observations from October 1, 1892, to October 1, 1893, indicated that the total loss from water surface during the warm months, together with that from snow and ice in the tank during the cold months, was over 46 inches, and other observations since that time indicate that the annual evaporation will range from this amount to as much as 60 inches. In single months which are dry and windy during the growing season, evaporation of from 7 to 10 inches is not uncommon. For the year evaporation from water surface amounts to four or five times the amount of rainfall, and in single months it may be twenty-five or thirty times the amount of water supplied by precipitation. The loss from streams, ditches, and reservoirs in the arid region from this cause is enormous. A loss of 4 feet from a reservoir or ditch covering 1 *square mile* of surface means the disappearance of enough water in a

year to irrigate over a thousand acres.[1] Many soils retain moisture for a longer period of time than it would take the same amount of water to evaporate from water surface. Their ability to retain their moisture depends upon chemical and physical characteristics. As Hilgard has pointed out, soils which contain large amounts of alkali salts always appear more moist than surrounding soils upon which salts have not accumulated. Unfortunately few observations on evaporation from soils, which will apply to arid conditions, are available.

UNITS OF MEASUREMENT.

That the measurements here reported may be fully understood by those who are unacquainted with irrigation, the following brief definitions of terms are given:

In measurements to determine the supply in streams and the amount used in irrigation the second-foot is universally adopted. The second-foot is the flow of 1 cubic foot of water for each second of time and is a most convenient unit, easily reduced to any of the terms in which quantity of water is expressed. It amounts to approximately 62.5 pounds or 7.8 gallons each second. One cubic foot per second continuous flow for 12.1 hours equals 1 acre-foot, i. e., enough to cover 1 acre 1 foot deep, or 43,560 cubic feet.

Over perhaps the largest part of the irrigated region of the West the unit of measurement into laterals from canals is the "miner's inch." This unit is supposed to represent the amount of water flowing through an aperture 1 inch square under conditions defined by law. Usually the opening is so placed that there is a certain depth of water above the opening, known as the pressure head. In some places the water is measured to users with no pressure head; in other places a pressure of 4 inches is given, and in still others a pressure of 6 inches. In point of fact, there is little uniformity in the use of the miner's inch, and there is a corresponding variation in its value. There are two forms of the miner's inch--the California inch and the Colorado inch—which differ in value. Fifty California miner's inches is equal to 1 second-foot, while 38.4 Colorado inches is equal to 1 second-foot. In actual practice the methods of measuring out the miner's inch probably cause variation in the amount of water greater than the difference in size of the Colorado and California standards. Without a complicated device it is difficult, if not impossible, to control the

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[1] An article was published in the Monthly Weather Review for September, 1888, giving a large number of determinations of evaporation through the year in various parts of the United States. In general, the evaporation was less than the rainfall in the humid States. The smallest evaporation recorded was 18.1 and 19.1 inches on the North Pacific coast. The maximum amounts were 101.2 inches at Fort Grant; 100.6 inches at Keeler; and 95.7 inches at Yuma, on the Southern plateau. At Fort Custer, Mont., it was 52 inches; at Cheyenne, 76.5; and at Denver, 69 inches.

depth of water above the opening, and small variations in this pressure head produce appreciable differences in the amount flowing through the opening. In California the duty of water is often expressed in the number of acres for which 1 inch continuous flow is sufficient, as statements are often met that 1 inch is sufficient for 5, 8, 10, or 12 acres.

HOW THE MEASUREMENTS WERE MADE.

Measurements of water are of little or no value unless they are accurately made. There are two methods of making trustworthy measurements in common use. That usually adopted in measuring streams is to obtain the velocity of the current in feet per second by means of an instrument designed for the purpose, and multiply the velocity by the area of the cross section of the stream in square feet, which gives the number of cubic feet flowing by in each second of time. An appropriator in Wyoming is required to place a box in his ditch in which the cross section of the stream can be easily determined and the velocity measured at any time. In order to obtain a continuous record we must furnish an instrument which will record the time of flow and fluctuations in depth, in which case it is necessary to know from actual determination the average velocity of the stream for each depth, if there is much rise and fall. Where there is much sediment in the water, or where the conditions are such that a measuring weir can not be located, the amount of water used can be determined with such a box and recording instrument.

All the measurements made by the Wyoming station and reported in this bulletin were made over a weir, which does away with the necessity of making determinations of average velocities of the stream. The Cippoletti trapezoidal weir, in which the sides are inclined at one-fourth horizontal to one vertical, was adopted. In order to fulfill the conditions necessary for accurate measurement, large boxes 6 feet square and 3 feet deep were constructed (Pl. I, fig. 1). The water from the lateral runs into the rear end of the box and out over the weir, which is placed in the forward end. A notch for the weir is made in the middle of a wide board which fits into the end of the box between cleats, like a gate, so it can easily be removed and a board with different length of weir used, if needed. This is found convenient, as the depth of the water flowing over the weir should not be less than 3 inches nor more than one-third the length of the weir. Then, if a large head of water is needed in the irrigation, a long weir may be used, and if only a small head is required a shorter weir is substituted, which arrangement may often overcome sources of error in the measurements. To give sharp edges to the sides and crest of weir used, strips of galvanized iron were screwed onto the side from which the water came, leaving the crest or base of the weir 12, 18, or 24 inches long

FIG. 1.—A WEIR BOX, SHOWING A NOTCH FOR A 1-FOOT WEIR BEFORE BEING SET IN LATERAL, WYOMING EXPERIMENT STATION.

FIG. 2.—MEAD WATER REGISTER AND WEIR IN USE AT THE WYOMING EXPERIMENT STATION.

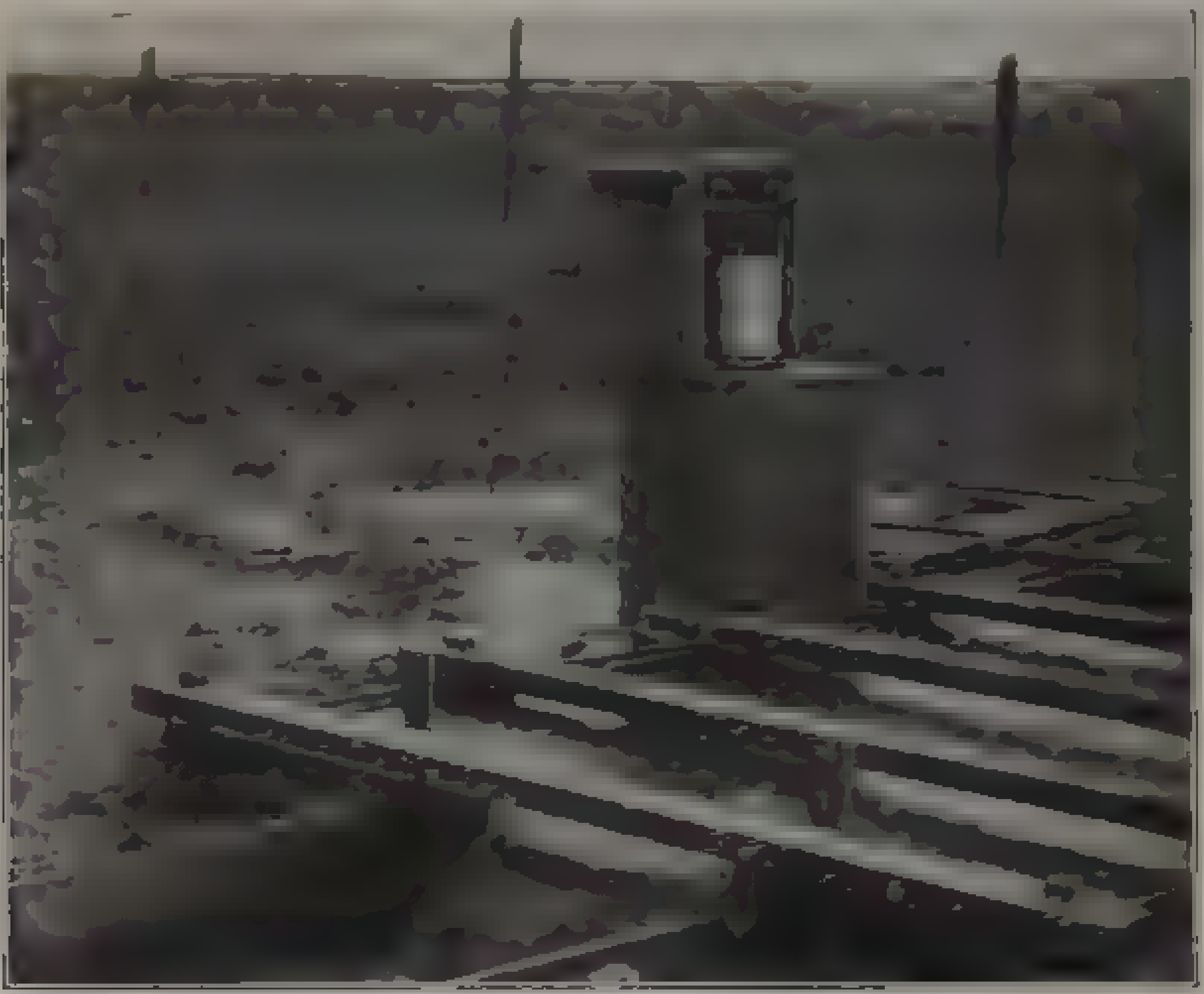

FIG. 1. WYOMING NILOMETER AND WEIR IN USE AT THE WYOMING EXPERIMENT STATION. BEYOND THE REGISTER THE CHARACTER OF THE UNIRRIGATED PLAINS IS SHOWN.

FIG. 2.—WYOMING NILOMETER AND WEIR IN USE ON A FARM NEAR LARAMIE, WYO.

This form of weir has two important advantages over the rectangular weir in which the sides are vertical. In weirs of different lengths the discharges are proportional to the lengths, i. e., the amount of water flowing over a 2-foot weir will be twice that flowing over a 1-foot weir, with but a small error, the depth remaining the same, and the slope of the sides is such that no coefficient for end contractions need be used in the formula, which makes the computations much easier. The formula for computing the quantity of water running over the trapezoidal weir is $D=3.3\frac{6}{9}\ L\ H^{\frac{3}{2}}$, in which D equals the discharge in cubic feet per second, L is the length of the weir in feet, and H equals the depth of the water flowing over the weir in feet.

A water register is used to give a record of the time the water flows over the weir and its depth. The water register consists of a clock to keep the time, a cylinder or disk upon which the paper which is to receive the record is placed, and a float in the water, either attached to the cylinder or a marking pen to record all variations in the depth of the water. The clockwork may either turn the cylinder and the pen be moved lengthwise of the cylinder as the float rises and falls, or the pen may be propelled by the clockwork and the cylinder revolved forward or backward by the changes in height of the float. It would seem that so simple an instrument could be manufactured at small cost, but the accuracy required in these instruments renders any so-called cheap register yet devised of little value. We have used several different patterns of water registers. The first instrument used by the Wyoming Station was the Wyoming nilometer, designed by Elwood Mead (Pl. II). This instrument, which has given very satisfactory results, consists of a vertical cylinder turned by a clockwork at the top and a pen moved up and down by a float attached to a line running over a pulley. A new register, also designed by Elwood Mead, for the irrigation investigations of the Office of Experiment Stations of the U. S. Department of Agriculture, is now used in making water measurements on the Wyoming Experiment Station farm (Pl. I, fig. 2). In this the cylinder is placed horizontally, and is turned by a line passing around one end and attached to the float, while the recording pen is caused to travel along the cylinder by clockwork. For a number of years we used a cheap register designed by D. A. Carpenter, in which the record is made on a dial turned by the clock. The chief objection to this instrument is the amount of work required to compute the records. A very good instrument is made in Paris, France. The pen describes an arc lengthwise of a cylinder, which is turned by the clock. The records on the register sheets which accompany this instrument are based on the metric system.

In using any register it is important to see that the clock is always in order and keeping good time, and the base line on the record, which is the line corresponding to the height of crest of the weir, must be

carefully located on each sheet. The float may change in buoyancy or the line from the float to the cylinder or pen may stretch or slip. With an 18-inch weir an error of one twenty-fifth of an inch in recording the depth of the water may cause an appreciable error in the computed amount. Accurately determining the point on the record sheet which corresponds to the crest of the weir is more difficult than it at first appears. When the water is high enough in the weir box to begin running over the crest of the weir the pen will be above the true base line, because the surface tension of the water causes it to pile up in front of the weir and lift the float an appreciable amount before the water will run over the sharp weir crest. A point on a level with the crest of the weir should be located near the float which is attached to the register, and when the water reaches this point the position of the pen will indicate the true base line on the record sheet. We have found a simple device to indicate the base line at any time a most convenient and valuable addition to the registers in use, and one has been made which will be incorporated in a new water register which has been planned for the Wyoming Station. A second float, to which a vertical rod is attached, was placed in the weir box. On this rod was placed a scale with a set screw to fasten it at any height desired. When the water in the weir box reached the height of the crest of the weir the zero point on the scale attached to the rod was set to correspond with a permanent point fixed in the register box, after which the depth of the water flowing over the weir could be read at a glance at any time and checked on the record sheet.

COMPUTING THE RECORDS.

The first step in computing records is to determine the depth recorded and the length of time the water ran at each depth. Small variations of less than an inch may be averaged; but where there is any considerable change, flowing for an appreciable length of time, the flow must be computed for such different depths and times separately. On record sheets where depth has been recorded by the pen moving in a straight line up and down, the average depth for a given time is easily obtained by the use of the planimeter, which gives the area of the figure. Knowing the area and the base of the figure, its average altitude, corresponding to mean depth of the water, would equal the area divided by the base. The flow in cubic feet per second at any depth can be obtained by applying the formula given on page 25, or by the use of tables which have been computed for the purpose.

DUTY OF WATER.

DEFINITIONS AND GENERAL CONSIDERATIONS.

What is meant by the duty of water.—The duty of water is an expression of the amount used to irrigate a given area. The great value of knowing the duty of water lies in the fact that it furnishes a means of determining the ratio between the water supply and the area which that supply will bring under profitable cultivation. The duty must be known before the size of the canal which is to carry water for a certain area can be determined. If all the facts regarding the duty of water for the crops raised were known, the greatest economy could be secured both in the construction of the necessary works and the application of the proper amount of water to produce the best results.

In the work of the Wyoming Station the crop factor has always been taken into account, and unless crops were matured the measurements of the water used have not been reported as duties. In 1893, when crops at the station failed because of the dry year and the lack of water in the first part of the season, the measurements were not reported as duties because enough water was not used to accomplish the results for which irrigation was practiced. Such measurements, if reported, would be misleading, as they would in no way represent the amount of water which must be supplied the irrigator in order to enable him to do profitable farming.

Terms in which duty is expressed.—There are several ways in which the duty of water may be stated. The usual method in vogue up to the present time has been to give the number of acres which a flow of a cubic foot per second will irrigate. This depends upon the length of the irrigating season, which is a varying factor. The length of the irrigating season usually adopted in expressing duty is four months (May, June, July, and August) or one hundred and twenty-three days. Sometimes ninety-five days is used, which more nearly corresponds with the length of the growing season. This is a purely arbitrary factor and one which causes considerable confusion, as it does not at once convey a definite idea of the amount of water used. The irrigating season is not necessarily synonymous with the growing season, though it is sometimes understood as the time from the first to the last irrigation of a given crop. In case of winter irrigation, which is acknowledged to be a good practice and often necessary with orchards and where the soil is used as a storage reservoir to save the moisture, the irrigating season would cover the whole year. The necessity of adopting a given length of time for all crops makes the expression of duty in acres per second-foot inaccurate. In the opinion of the writer the better method of expressing duty is to give the total amount used

per acre for each crop. This may be expressed in acre-feet, or what is equivalent, in the depth to which the water used will cover the land; or again, in the total number of cubic feet used upon an acre of land. As the amount of water is so intimately associated with the rainfall, it seems that the total depth of water received by the land during the season, both from irrigation and rainfall, with information of the rainfall during the rest of the year, gives a more definite and satisfactory idea of what is required by each crop. In this bulletin the duties are expressed in the several ways mentioned in order that a definite idea may be obtained of the amount of water used and that these duties may be compared with those reported by other writers.

Duty of water variable. The duty of a continuous flow of a cubic foot of water per second has been reported for different crops and different places, ranging all the way from a minimum of one-half acre in France, 1 to 18 acres in Italy,[1] and 7 acres in California,[2] to a maximum of 2,200 acres in Spain. Expressed in the depth to which the water would cover the land, this gives a minimum of less than 3 inches and a maximum of 1,400 feet in a year. In one case, where sewage was used for irrigation on sandy and gravelly soil near Paris, enough was supplied during the season to cover the land to a depth of 38.2 feet.[3]

The duty determined so far in Wyoming, calculated on the basis of one hundred and twenty-three days as the irrigating season, varies with different crops and in different years from 65 acres with native hay to 908 acres with potatoes.

The duty of water is sensitive to many modifying conditions. It varies with the character of the soil and the subsoil; with the slope and the smoothness of the land; with the amount of land; with the length of time the soil has been cultivated and irrigated; with the presence or absence of water supply from below; with the rainfall and its distribution through the year; with the altitude, temperature, wind, and other conditions affecting water movement, evaporation, and crops; with the kind of crop; with the length of the irrigating season and the diversity of crops, which enables rotation in the application of water in order to keep it constantly in use; and with the skill and economy of the irrigator.

Wherever there is waste it must be made good by drawing on the supply. Water may be lost by escaping from the surface instead of being absorbed by the soil during the time irrigation is being done, or it may be lost by seepage through a porous subsoil. After the water

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[1] Flynn's Irrigation Canals, p. 293.

[2] Irrigation at Bakersville, Cal.; Water Supply and Irrigation Papers No. 17, U. S. Geological Survey.

[3] Sewage Irrigation; Water Supply and Irrigation Papers No. 3, U. S. Geological Survey.

has been applied it is continually being lost through evaporation from the surface, and where evaporation is great more water will be needed. Therefore different methods of irrigation and cultivation may make a great difference in the duty of water on the same soil and crop. In studying duty it is therefore important to have a record of all these modifying conditions.

DUTIES FIRST DETERMINED IN WYOMING.

The first measurements to determine the duty of water in Wyoming were made by the Territorial engineer, Elwood Mead, in 1889, at Wheatland. The results reported below are taken from the second annual report of the Territorial engineer.

Quantity of water used on oats and potatoes at Wheatland, Wyo., in 1889.

Rainfall and irrigation.	April.	May.	June.	July.	August.	Irrigating season.
Oats:	*Inch.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Depth of rainfall	0.50	3.45	3.37	1.99	0.75	10.06
Depth of irrigation	....	....	7.236	21.936	2.124	31.296
Irrigation and rainfall	.50	3.45	10.606	23.926	2.874	41.356
Potatoes:						
Depth of rainfall	.50	3.45	3.37	1.99	.75	10.06
Depth of irrigation	....	....	....	12.744	....	12.744
Irrigation and rainfall	.50	3.45	3.37	14.734	.75	22.804

SUMMARY.

Item.	Oats.	Potatoes.
Total amount of water used ... cubic feet..	14,056,235.55	323,825.
Time employed ... days..	54.5	1.5
Area of surface ... acres..	123.7	7
Average discharge for period used ... cubic feet per second..	3.79	2.5
Equivalent average discharge for irrigating season of four months (May, June, July, August) ... cubic feet per second..	1.32	.0305
Or an equivalent duty of 1 cubic foot per second for continuous discharge ... acres..	93.8	229.5

In the discussion of the above results it is stated that—

The depth of the water spread over the surface in July (nearly 2 feet) seems unnecessarily large, and to those unacquainted with the enormous evaporation which takes place during the summer months it would seem that such a volume of water would be ruinous. The results, however, sustain the judgment of the irrigator. Part of the field was damaged by hail, yet the average yield was 40 bushels per acre, and 1 measured acre in the unharmed portion gave a yield of 75 bushels.

The potatoes upon which water was measured gave a yield of 150 bushels per acre.

Measurements of water made at Laramie and at Wheatland by the Wyoming Station in 1891 and 1892 have been reported.[1] As the duties are closely related to those afterwards obtained on the same lands and

[1] Wyoming Sta. Bul. 8.

reported in the following pages they are repeated in the next table. The land on which these experiments were made was sod, broken in the spring of 1891. The sugar beets and ruta-bagas, corn, cane, peas, and beans were planted in rows and irrigated in furrows. All other crops were irrigated by flooding.

Duty of water, Wyoming Experiment Station, 1891–92.

Place.	Crops.	Yield per acre.	Rainfall for four months.a	Date irrigated.	Total amount of water used.	Average depth of irrigation water on land.	Duty of 1 cubic foot per second continuous flow.
1891.			*Inches.*		*Cubic feet.*	*Inches.*	*Acres.*
Laramie	Mixed		6.16		2,667,288.75	30.6	96.62
Wheatland	Oats	40 bushels.	3.50	June 20 to July 12.	9,507,078.47	17.4	167.60
1892.							
Laramie	Sugar beets / Ruta-bagas	8.6 tons / 18 tons.	b 6.99	June 16, 17; Aug. 16; Sept. 22	97,973.24	9.9	299.77
Do	Corn	Cut for fodder.	b 6.99	July 20	10,848.39	4	735.29
Do	Cane, durra		b 6.99	July 23	19,754.92	8.7	336.02
Do	Peas, beans	7 bushels	b 6.99	June 5	18,081.13	4.9	588.22
Do	Mixed		b 6.99		1,180,511.41	13.5	216.06

a Four months of growing season—May, June, July, and August.
b 5.13 inches fell in May and June.

DUTIES FOR DIFFERENT CROPS.

The amount of water required by different crops varies enormously. In desert regions where the rainfall does not exceed 4 or 5 inches, while evaporation would amount to more than 100 inches if there were water to evaporate, there are many kinds of plants which live and when supplied with a small amount of water produce flowers and fruit. During the greater part of the year, when no water is available, they merely suspend growth. On the other hand, there are plants which will not live unless continuously standing in water or having the larger part of their roots and stems completely covered with it. In the different varieties of the same kinds of plants there is marked difference in ability to stand drought and to produce a crop with a scanty water supply. A variety of oats which needs only ninety days to mature its grain and which throws all its force into the production of seeds rather than straw will produce a crop with a small part of the water required by a variety taking one hundred and eighty days to mature and producing long, coarse straw. The two extremes have actually been observed at Laramie. Many plants also have the power to adapt themselves to the soil and climate. Oats will grow in the Tropics or in a region marked by frosts every month of the year. Such changes in the plant may change its requirements somewhat, so that the duty for the same crop will undoubtedly vary according to variety and such conditions of adaptation as may have become established.

Although irrigation has been practiced for centuries, it is still of

first importance to know how much water is actually used on crops, when it is used, and with what results, before we can know where improvement is possible. We can not say that the duties so far obtained are the true amounts which are necessary to produce maximum crops, although where large crops result the judgment of the irrigator is sustained.

RECENT EXPERIMENTS ON THE DUTY OF WATER.

Measurements have been made at the Wyoming Experiment Station every year since those reported in 1891 and 1892, but those made at Laramie in 1893 and 1894 are omitted from this report, as they were incomplete and inaccurate. At Wheatland a careful series of measurements were made for us in 1893 by Mr. M. R. Johnston, superintendent of the substation at that place. The data at hand not before published, which was obtained by measurements at Wheatland in 1893 and at Laramie during the years 1895 to 1898, inclusive, are reported below. All the computations have been reduced to the acre standard. The measurements were made on areas varying from a fraction of 1 acre to 50 acres.

HAY CROPS.

The larger part of the land irrigated in Wyoming is for the production of winter stock food, and the amount of water used in the production of hay crops is of great interest and importance. The following gives the results of our measurements on hay land up to the present time:

Duty of water, hay crops.

Crop.	Place.	Year.	Water received by irrigation per acre.		Depth of water supplied land by irrigation and rainfall.		Duty of 1 second-foot for season.		Yield per acre.
			Quantity.	Depth over surface.	Growing season.	Year.	Four months	Ninety-five days.	
			Cu. ft.	*Feet.*	*Feet.*	*Feet.*	*Acres.*	*Acres.*	*Pounds.*
Alfalfa, two crops.	Laramie....	1896...	47,356	1.09	1.49	2.02	224.4	173.2	4,664
Alfalfa, first year.	.....do......	1898...	129,388	2.97	3.35	3.61	82.1	63.4	2,220
Alfalfa, two crops.	.....do......	1898...	113,101	2.60	2.98	3.24	94	72.6	8,668
Alfalfa, three crops	Wheatland.	1893...	113,184	2.60	2.75	3.13	93.9	72.5	15,752
Brome grass, first year.	Laramie....	1898...	129,811	2.98	3.36	3.62	81.9	63.2	....
Native hay.......	.....do......	1898...	174,240	4	4.38	4.64	61	47.1	....
Oats and vetch...	.....do......	1898...	68,753	1.58	1.96	2.22	151.7	119.4	5,563
Timothy..........	Wheatland.	1893...	102,384	2.35	2.50	2.88	103.8	80.2	2,212

With one exception the duties determined are on cultivated hay crops. In every instance the irrigation was by flooding the land at intervals through the season. As a rule, hay crops occupy the land permanently, have a long season of growth, and require more water than common farm crops. While the ground is shaded the larger part of the time, which prevents excessive loss by evaporation from the

ground, no method of cultivation to hold the moisture in the soil can be practiced, and large amounts of water are evaporated from the plants, which cover the entire land surface.

It will be noticed that alfalfa, the first year after the seed was planted, received more water than that which had occupied the land more than one year. Newly plowed ground absorbs a large amount of water and frequent irrigations are necessary the first season to get the young plants established. At Laramie in 1896 a small amount of water was used on the alfalfa. The yield that year was also comparatively small and it is not unlikely that more water would have increased the crop. At Laramie only two crops can be cut in a season, while three crops are obtained at Wheatland. As a rule, alfalfa requires more water than cultivated crops other than hay, but is not watered so much as native meadows. The measurement of water used on native hay reported in the table was made on a private farm near Laramie. It was the first year the native sod was irrigated to turn it from pasture to meadow, and while a large amount of water was used it is probable that under the conditions none too much was applied. The grass made good growth, some of it being heavy enough for hay. The soil is composed of loose gravel and sand, extending to a depth of about 10 feet. The water runs through and drains off from below with great rapidity and ease, so it is necessary to irrigate often to keep the surface soil sufficiently moist to force a growth of the native grasses. Seepage through this soil is so great that while water was applied to only 48.9 acres a good crop of wheat was raised with only a partial irrigation and crops of oats and potatoes with no direct application of water, they being supplied by seepage from the ditches and adjacent land. The area of land actually supplied with water was 52 acres, enough being used to cover the total area to a depth of 3.76 feet. Computing the duty of 1 second-foot for four months on this basis would raise it to 65 acres. It should be stated that large amounts of water are needed for the first few years to stimulate native sod so it will produce sufficient crops of hay to be harvested. After the land begins to produce good crops, however, the amount of water and the method of applying it must be modified with some judgment. Often too much water is used on old meadows, being run over the land continuously. All our farmers admit that the low places on their land which receive the most water become filled with "water grass" (species of Beckmannia, Sporobolus, Spartina, Panicularia, Elymus, Catabrosa, Deschampsia, Distichlis, etc.), or "wire grass" (Juncus), or "three-cornered grass" (Carex), or foxtail (Hordeum), few of which make first-quality hay, and on many ranches the greater part of the hay produced consists of these inferior kinds. The better upland grasses are simply drowned out by the excess of water or killed by the accumulation of alkali salts on the surface. The best irrigators give

FIG. 1.—BONANZA OATS FLOOD-IRRIGATED ON THE WYOMING EXPERIMENT STATION FARM. RECEIVED 22.8 INCHES OF WATER.

FIG. 2.—VARIETIES OF GRAIN FURROW-IRRIGATED AT THE WYOMING EXPERIMENT STATION. RECEIVED 18.36 INCHES OF WATER.

the land a thorough soaking, being careful not to let too much accumulate on the lower portions, then turn it onto an adjoining field, allowing the first land irrigated to have a growing and "breathing spell," alternately irrigating one field after another until all have received from four to eight soakings in the season.

On account of the short growing season none of the perennial hay plants will produce a full crop the first season from seed. Alfalfa will produce a small crop the first summer, but as a rule it takes more than one season to secure profitable crops of alfalfa, native hay, or other permanent forage plants. The brome grass, on which measurements were made in 1898, took a comparatively large amount of water; but being the first year from seed, a sufficient crop to pay for harvesting was not produced. The amount of water used on timothy at Wheatland is of interest, and oats and vetch for hay at Laramie produced a good crop with only a comparatively small amount of water.

GRAIN CROPS.

All the duties determined since 1892 for different kinds and varieties of grains (Pl. III) are given in the following table:

Duty of water, grain crops.

Crop.	Place.	Year.	Water received by irrigation, per acre.		Depth of water supplied land by irrigation and rainfall.		Duty of 1 second-foot for season.		Yield per acre.
			Quantity.	Depth over surface.	Growing season.	Year.	Four months.	Ninety-five days.	
Barley:			*Cubic feet.*	*Feet.*	*Feet.*	*Feet.*	*Acres.*	*Acres.*	*Pounds.*
Three varieties.	Wheatland	1893	39,744	0.91	1.06	1.44	267.4	206.5	864
Nine varieties	Laramie	1895	52,895	1.21	1.88	2.14	200.9	155.1	896
Highland Chief.	do	1898	117,711	2.70	3.08	3.34	90.3	69.7	1,392
Corn, Minnesota King.	Wheatland	1893	47,520	1.09	1.24	1.62	223.6	172.7	3,189
Oats:									
Giant Side	do	1893	76,896	1.77	1.92	2.30	138.2	106.7	1,603
Early Archangel.	do	1893	68,256	1.57	1.72	2.10	155.7	120.3	1,024
Lincoln, Surprise, Bonanza	Laramie	1898	82,647	1.90	2.28	2.54	128.6	99.2	*a*1,688
Lincoln (on sod).	do	1898	112,579	2.58	2.96	3.22	94.4	72.9	698
Surprise (subsoiled).	do	1898	160,835	3.69	4.07	4.33	66.1	51	1,634
Rye:									
Spring	Wheatland	1893	56,160	1.29	1.44	1.82	189.2	146.2	974
Winter	do	1893	38,448	.88	1.03	1.41	276.4	213.5	739
Spring	Laramie	1898	58,123	1.33	1.71	1.97	182.8	141.2	556
Wheat:									
White Russian	Wheatland	1893	69,984	1.61	1.76	2.14	151.9	117.3	1,962
Fultz Winter	do	1893	41,040	.94	1.09	1.47	258.9	200	486
Five varieties	Laramie	1898	158,001	3.63	4.01	4.27	67.3	51.9	*b*1,573

a Average yield of the three varieties.

b Average yield of the five varieties.

There is considerable variation in the duties on the same kind of grain due to various causes, such as difference in soils, in location and in other modifying influences. No doubt much of the varia... in this table (and in others as well) is due to pure accident ... considers a thorough irrigation the irrigator will ... different quantities of water at different times or ... at the same time. No doubt different amounts have ... good or bad, on the resulting crop, but without definite ... these influences may be the irrigator simply uses ... the number of times to irrigate and the amount of ... irrigation. At Laramie barley was given over ... 1898 as was applied in 1895. The rainfall was ... 1898, but the amount was not sufficiently ... of water received by the two crops. In ... rainfall, the crop of 1898 received more ... of that in 1895. There was an increase ... irrigation, but not a proportional one. ... amount of water applied to two different ... 2 inches in depth. The variation ... different soils is very marked, and will be ...

... water used on winter and spring ... table. Winter rye at Wheatland ... water as spring rye, and the differ... amounts applied to winter and ... fall may be kept alive by the ... months and be brought to early ... the spring months along with a ... dry that winter grain is very

SUGAR BEETS FURROW-IRRIGATED AT THE WYOMING EXPERIMENT STATION. RECEIVED 19.2 INCHES OF WATER.

ROOT CROPS.

The only root crops on which duties have been determined are potatoes, turnips, and sugar beets (Pl. IV). The results of measurements on these crops are as follows:

Duty of water, root crops.

Crop.	Place.	Year.	Water received by irrigation, per acre.		Depth of water supplied land by irrigation and rainfall.		Duty of 1 second-foot for season.		Yield per acre.
			Quantity.	Depth over surface.	Growing season.	Year.	Four months.	Ninety-five days.	
			Cubic feet.	*Feet.*	*Feet.*	*Feet.*	*Acres.*	*Acres.*	*Pounds.*
Potatoes	Laramie	1895	11,683	0.27	0.95	1.20	909.6	702.6	9,000
Do	...do	1896	13,866	.32	.72	1.22	766.5	592	....
Do	...do	1897	26,237	.60	1.01	1.60	405	312.8	....
Potatoes, 3 irrigations.	...do	1898	49,825	1.14	1.54	1.78	213.3	164.7	8,675
Potatoes, 2 irrigations.	...do	1898	12,925	.30	.68	1.94	822.2	635	5,131
Potatoes, 22 varieties.	Wheatland	1893	61,776	1.42	1.57	1.95	172	132.9	7,344
Sugar beets and ruta-bagas.	Laramie	1898	69,875	1.60	1.98	2.24	152.1	117.8	....
Sugar beets, 4 varieties.	Wheatland	1893	107,128	2.46	2.61	2.99	99.2	76.6	12,912
Turnips and ruta-bagas.	Laramie	1895	112,733	2.59	3.27	3.52	94.3	72.8	....

These crops were all irrigated in furrows, so the water used reached the plant roots from the sides of the furrow or from below, without allowing the water to come against the stem or top of the plant. It will be noticed that potatoes received comparatively small amounts of water, while sugar beets and turnips were much more heavily irrigated. In all the instances reported in which potatoes did not receive more than three-tenths of a foot of water, the irrigation can be considered only a partial watering of the land and crop. A complete irrigation or thorough soaking of the soil can not be done with such small amounts of water, at least under our conditions. By proper cultivation and management we have succeeded in raising very good crops of potatoes on the Laramie plains without irrigating the crop, though it was on old land which had been irrigated in previous years, and which undoubtedly contained considerable surface water. From the table it appears that there has been quite a steady increase in the amount of water used on potatoes at Laramie, and in the same year there was a marked increase in the yield of a plat receiving 1.14 feet of water over the plat which received only 0.3 foot. Too much water, however, is very injurious to the quality of potatoes; so much so that Laramie merchants refuse to buy potatoes known to have been raised on land which is kept too wet. In the measurements reported, however, we have no evidence that too much water was applied.

MIXED CROPS.

It has not been found practicable to measure the water used on each separate plat or field, and often several kinds of crops have been grown on the same plat, all of which were irrigated at the same time. Usually we have kept separate records of the water used on each kind of crop. For instance, we often irrigate several kinds of grain at the same time and keep a record of the amount of water used for the whole. The results of measurements for mixed crops are given in the table below. This table also contains the duties for different crops of peas and flax.

Duty of water, mixed crops—Grains, peas, and flax.

Crop.	Place.	Year.	Water received by irrigation, per acre.		Depth of water supplied by irrigation and rainfall.		Duty of 1 second-foot for season.	
			Quantity.	Depth over surface.	Growing season.	Year.	Four months.	Ninety-five days.
			Cu. feet.	*Feet.*	*Feet.*	*Feet.*	*Acres.*	*Acres.*
Grains, root crops, hay, and garden.	Laramie	1895	50,266	1.15	1.82	2.08	211.4	163.3
Wheat, 18 varieties; oats, 3 varieties.	do	1896	52,895	1.21	1.61	2.11	200.9	155.2
Barley, oats, and wheat	do	1896	63,296	1.45	1.85	2.35	167.9	129.7
Garden (furrow irrigated)	do	1896	54,270	1.25	1.65	2.15	195.8	151.2
Grain (wheat, oats, barley, furrow irrigated).	do	1896	61,122	1.40	1.80	2.30	173.9	134.3
Wheat and oats (sod land)	do	1896	41,886	.96	1.36	1.86	253.7	196
Wheat (Blount No. 16), oats (Lincoln).	do	1897	107,012	2.46	2.87	3.46	99.3	76.7
Oats, rye, barley, and flax	do	1897	69,345	1.59	2	2.59	153.4	118.4
Grain (varieties furrow irrigated).	do	1897	66,467	1.53	1.94	2.53	159.9	123.5
Oats (Surprise and grains furrow irrigated).	do	1898	67,477	1.55	1.93	2.19	157.5	121.6
Wheat (Blount No. 16), oats (Lincoln).	do	1898	75,853	1.71	2.12	2.38	140.1	108.2
Peas	do	1897	74,699	1.71	2.12	2.71	142.3	109.9
Do	do	1897	136,408	3.13	3.54	4.13	78	60.2
Do	do	1898	124,304	2.85	3.23	3.49	85.5	66
Barley (Highland Chief), wheat (Scotch of Scotch).	do	1898	75,159	1.73	2.11	2.37	141.4	109.1
Oats, rye, barley, and flax	do	1897	69,345	1.59	2	2.59	153.3	118.4
Flax, 2 varieties	Wheatland	1893	95,040	2.18	2.33	2.71	111.8	86.4

In 1895 but few separate records were kept, but the total amount used on the station farm was determined and shows that enough water was used to cover all the land cultivated to a depth of 1.15 feet. The season of 1895 was unusually favorable at Laramie, all crops succeeded well, and only small amounts of water were used. The irrigation was by flooding for grains and hay and by the furrow method for root crops and garden.

In most instances where different grains are reported together, they were occupying the same field, which was all irrigated at one time and each crop received the same amount of water; so where wheat and oats, or wheat, oats, and barley are reported together, the duty is the same for each crop as it is for the combined crops. Unless otherwise stated the grains were irrigated by flooding. Where cultivated grain is

mentioned it refers to varieties of wheat, oats, and barley, which were planted with drills twice as far apart as the ordinary drill row and cultivated between the rows after each irrigation. These cultivated grains were irrigated by the furrow method. (Pl. III, fig. 2.) The garden duties reported in this table consisted of mixed garden crops such as peas, beans, celery, beets, turnips, lettuce, cabbage, etc.; and the duty for the garden represents the amount of water necessary for such crops. Yields are not given in this table, but no measurements are reported on land which failed to produce and mature a crop.

The duties given in this table, if we leave out the individual crops of peas, are more uniform than those given in the preceding table for single crops. As a rule these duties were determined from measurements of larger areas than those on separate crops, and it is likely that they more nearly represent the amounts of water which are used in average farm practice. Averages from the table give a duty of 154.6 acres for a continuous flow of 1 cubic foot per second for four months, or enough water used to cover the land to a depth of 1.578 feet.

CONDITIONS AFFECTING DUTY.

INFLUENCE OF CLIMATE AND RAINFALL ON DUTY.

The amount of water which must be applied to the land artificially in order to produce crops varies from none, where the rainfall is sufficiently great, to the maximum amount needed by soil and crop where there is practically no rainfall. As already stated, there is much variation in the quantity of water which is necessary for the same kind of plants growing in different places on the earth's surface. No doubt much may be done for the arid region of the West by introducing useful plants from other arid countries and by the actual production of varieties which will succeed with small amounts of moisture. A beginning has been made, and already we have drought-resisting wheat, short-season oats, and nonsaccharine sorghums which mature with little moisture, the Turkestan alfalfa, which withstands drought better than the common variety, and there are numerous plants growing on our dry plains which may become valuable when brought under cultivation. The West is still new, and the plants usually grown are those which have been introduced from humid regions. Such plants require comparatively large amounts of water supplied by irrigation. As varieties are produced which require less water the area which can be irrigated with the supply will be extended.

INFLUENCE OF METHODS OF IRRIGATION ON DUTY.

There are various methods of applying water to crops, which have been classified as flooding, furrow, bed, check, rill, seepage, and pipe, or subirrigation, systems. The amount of water required to mature

the plant remains the same, but there is considerable difference in the amount of waste in distribution, depending on the method by which the farmer furnishes the water to the plant. Whether one method is more efficient and economical than another depends upon a number of conditions, as kind of crop, slope and configuration of the land, kind of soil and subsoil, and the care and skill used in applying the water.

Subirrigation, where the water is applied to the lower layers of the soil by underground systems of pipes, is generally considered the most economical, as it eliminates two sources of loss—waste by running off from the surface and evaporation from open ditches. Two systems of subirrigation, one with iron pipe and the other with lines of porous tile laid deep enough in the soil to be below the plow, are in use at the Wyoming Station, but unfortunately the amount of water used in them has not been accurately measured. Our observation leads us to believe, however, that where the subirrigation pipes are located in loose, gravelly, and sandy subsoil the loss from seepage is greater than the ordinary losses observed when water is applied through open ditches. Systems of subirrigation have the advantage in requiring little care, and undoubtedly such systems are ideal where the surface soil absorbs water readily and allows its distribution to some distance from the pipe, and where the subsoil is such as to prevent great loss from seepage. The duty of a second-foot in pipe systems in California is said to be 500 acres and over.

By far the greater number of crops seem to thrive better when water is not allowed to come against the crown of the plants. Even plants, such as celery and cabbages, which are said to thrive in a saturated subsoil, are not benefited by standing directly in the flood, and potatoes, corn, tomatoes, and other plants show unmistakable injury if the water is allowed to come in contact with the stalks where they emerge from the ground. A matter of common observation is that grass and grain, which are usually irrigated by flooding, produce more thrifty growth on ditch banks and higher ridges and knolls where the roots are supplied by seepage from beneath rather than from flooding the surface. This fact has led in some localities to the adoption of the rill system with such crops as cover all the land. The rills or small streams are laid out on contour lines with a corn marker or other implement which will produce small parallel ditches, and the water is allowed to run through them for several days at a time until the land is well saturated. Tests of this method have shown that it is not practicable to irrigate thoroughly by means of it without a large waste at the lower side of the field. This system is practiced in parts of central Wyoming where there is abundant water supply. After the water has been distributed to the laterals little attention is required.

The bedding system is usually considered a very old and out of date, *but somewhat* economical, method of irrigation. After the dikes or

levees have been thrown up around each level field, at great labor and expense, little skill and attention are required further than to turn the water from one plat into another after it has stood a sufficient time to thoroughly wet the land. The check system, in which low dikes extend along the contour lines to facilitate flooding the land and prevent rapid waste of water, is an improvement on the bed system, at least for large areas.

Flooding is the system more generally adopted for such crops as forage plants and grains, which cover all or practically all of the land. The bed and check methods are modifications of flooding. With this system much depends on the configuration of the land and the skill of the operator, and men who become skillful in the application of water command higher wages and are always in demand. Under ordinary conditions the man who understands the business will irrigate with little or no waste. Where the slope is not too great, the surface even, with the soil permeable, and the head water supply adequate, not a drop will be allowed to escape from the land by running off the surface, and the efficiency of the water is as great as it could be under any other system of distribution. With a stiff clay soil, which absorbs water slowly, the head or flow used must be so modified as to allow time for the water to be taken up, but in loose sandy soils a large head is necessary to cover the land as soon as possible. In some instances the soil is so porous that it is necessary to fill it to a considerable depth before the water can be run over the surface, and in such cases large amounts of water are required. On loose or gravelly soil water usually has a small duty.

In furrow irrigation the water is run through channels plowed for the purpose between rows of plants, such as corn, potatoes, and like crops, which are planted sufficient distances apart. In this system it is possible, if so desired, to give partial irrigations—as, for example, by allowing the water to run through every other furrow for so short a time that not all the land between them is supplied. High duties are often obtained in this way, and the crop is said to be irrigated with an amount so small that it would be impossible to soak all the land with it. On the other hand, if the soil is thoroughly soaked at each irrigation, practically as much water is used as in any other method. In 1895 potatoes which were given only one furrow irrigation in the season apparently had a duty of 909.6 acres, while turnips irrigated in the same way gave a duty for four months' flow of only 94 acres. In 1897 and 1898 potatoes were irrigated with an amount of water which would cover the land to a depth of only from 1½ to 2 inches, while a thorough irrigation by flooding under ordinary conditions can probably not be accomplished with much less than 3 inches. In 1898 oats and wheat, planted in rows twice as far apart as with the ordinary drills and irrigated in furrows gave duties of 140 and 157.5 acres,

the land a thorough soaking, being careful not to let too much accumulate on the lower portions, then turn it onto an adjoining field, allowing the first land irrigated to have a growing and "breathing spell," alternately irrigating one field after another until all have received from four to eight soakings in the season.

On account of the short growing season none of the perennial hay plants will produce a full crop the first season from seed. Alfalfa will produce a small crop the first summer, but as a rule it takes more than one season to secure profitable crops of alfalfa, native hay, or other permanent forage plants. The brome grass, on which measurements were made in 1898, took a comparatively large amount of water; but being the first year from seed, a sufficient crop to pay for harvesting was not produced. The amount of water used on timothy at Wheatland is of interest, and oats and vetch for hay at Laramie produced a good crop with only a comparatively small amount of water.

GRAIN CROPS.

All the duties determined since 1892 for different kinds and varieties of grains (Pl. III) are given in the following table:

Duty of water, grain crops.

Crop.	Place.	Year.	Water received by irrigation, per acre.		Depth of water supplied land by irrigation and rainfall.		Duty of 1 second-foot for season.		Yield per acre.
			Quantity.	Depth over surface.	Growing season.	Year.	Four months.	Ninety-five days.	
			Cubic feet.	*Feet.*	*Feet.*	*Feet.*	*Acres.*	*Acres.*	*Pounds.*
Barley:									
Three varieties.	Wheatland	1893	39,744	0.91	1.06	1.44	267.4	206.5	864
Nine varieties	Laramie	1895	52,895	1.21	1.88	2.14	200.9	155.1	896
Highland Chief.	....do	1898	117,711	2.70	3.08	3.31	90.3	69.7	1,392
Corn, Minnesota King.	Wheatland	1893	47,520	1.09	1.24	1.62	223.6	172.7	3,189
Oats:									
Giant Side	....do	1893	76,896	1.77	1.92	2.30	138.2	106.7	1,603
Early Archangel.	....do	1893	68,256	1.57	1.72	2.10	155.7	120.3	1,024
Lincoln, Surprise, Bonanza	Laramie	1898	82,647	1.90	2.28	2.54	128.6	99.2	*a* 1,688
Lincoln (on sod).	....do	1898	112,579	2.58	2.96	3.22	94.4	72.9	698
Surprise (subsoiled).	....do	1898	160,835	3.69	4.07	4.33	66.1	51	1,634
Rye:									
Spring	Wheatland	1893	56,160	1.29	1.44	1.82	189.2	146.2	974
Winter	....do	1893	38,448	.88	1.03	1.41	276.4	213.5	739
Spring	Laramie	1898	58,123	1.33	1.71	1.97	182.8	141.2	556
Wheat:									
White Russian	Wheatland	1893	69,984	1.61	1.76	2.14	151.9	117.3	1,962
Fultz Winter	....do	1893	41,040	.94	1.09	1.47	258.9	200	486
Five varieties	Laramie	1898	158,001	3.63	4.01	4.27	67.3	51.9	*b* 1,573

a Average yield of the three varieties.

b Average yield of the five varieties.

There is a considerable variation in the duties on the same kind of grain due to various causes, such as difference in soils, in location and climate, and other modifying influences. No doubt much of the variation shown in this table (and in others as well) is due to pure accident. In giving what he considers a thorough irrigation the irrigator will apply widely different quantities of water at different times or to different fields at the same time. No doubt different amounts have influences, good or bad, on the resulting crop, but without definite knowledge of what these influences may be the irrigator simply uses his judgment as to the number of times to irrigate and the amount of water to apply at each irrigation. At Laramie barley was given over twice as much water in 1898 as was applied in 1895. The rainfall was greater in 1895 than in 1898; but the amount was not sufficiently great to balance the quantity of water received by the two crops. In fact, if we take account of the rainfall, the crop of 1898 received more than 1 foot of water in excess of that in 1895. There was an increase in the yield with the heavier irrigation, but not a proportional one.

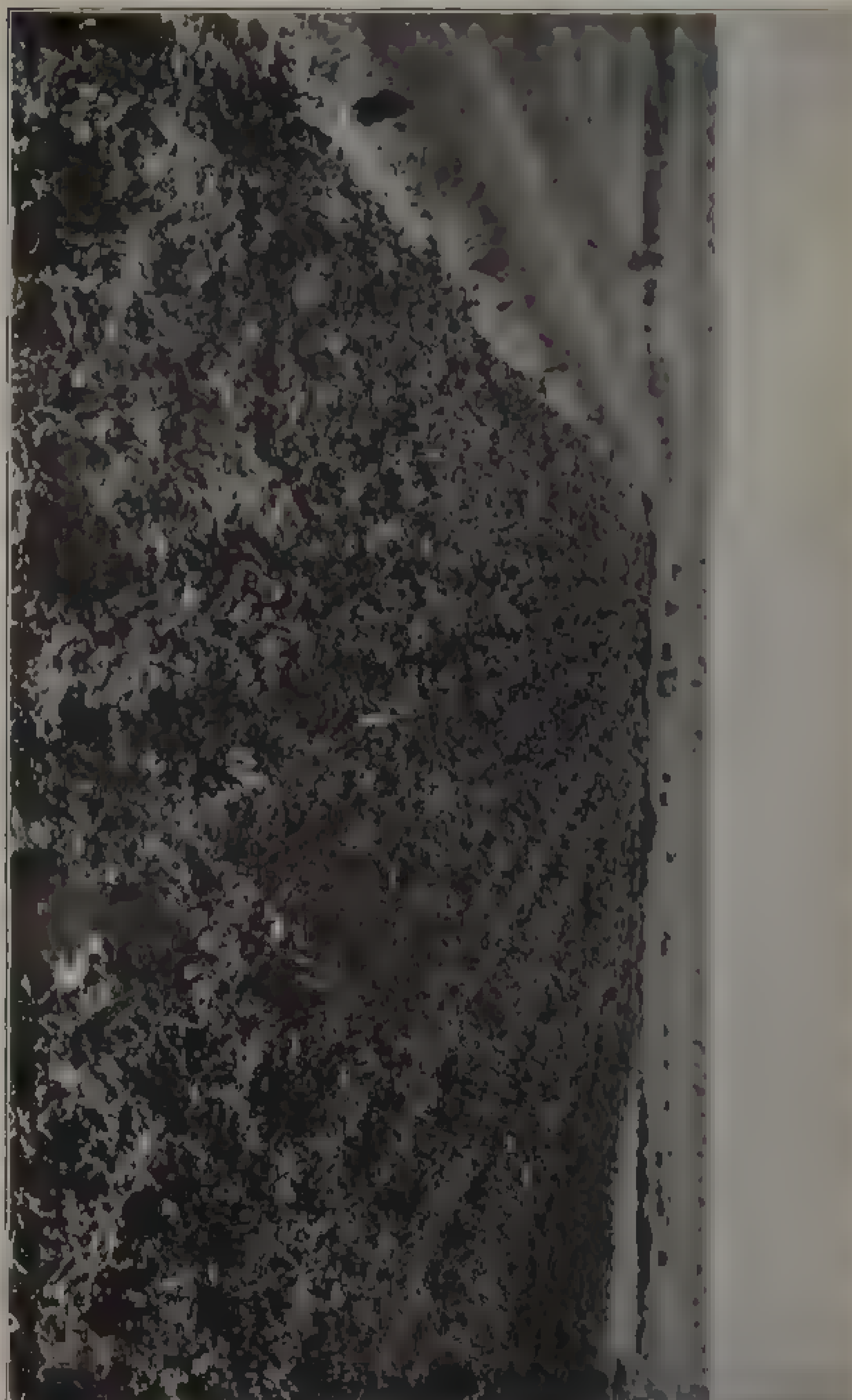
At Wheatland in 1893 the amount of water applied to two different varieties of oats varied by nearly 2½ inches in depth. The variation in amount of water used on different soils is very marked, and will be considered under a separate head.

The difference in the amount of water used on winter and spring grains is well brought out in the table. Winter rye at Wheatland received only two-thirds as much water as spring rye, and the difference is about the same between the amounts applied to winter and spring wheat. Grains planted in the fall may be kept alive by the scanty moisture through the winter months and be brought to early maturity by the heavier rainfall of the spring months along with a little irrigation. Our climate is so dry that winter grain is very uncertain, and when it does not actually die out in the winter only small crops are obtained. Winter rye is sufficiently hardy to do very well, but winter wheat is not a profitable crop.

The average depth of water used on grains where more than one measurement has been made, in Wyoming, including the measurements at Wheatland and Laramie before 1892 and those in the table on page 33, are as follows:

	Feet.
Barley	1.61
Oats, 7 measurements	2.22
Rye, 2 measurements	1.31
Wheat, 2 measurements	2.62

Oats and wheat require more water than either barley or rye, and no doubt rye can be produced with less water than any of the other cereals.



SUGAR BEETS FURROW-IRRIGATED AT THE WYOMING EXPERIMENT STATION. RECEIVED 19.2 INCHES OF WATER.

One of these says he does some fall irrigating and he believes he can make beneficial use of the water for the period from April 15 to November 15. One man on the Laramie plains has no irrigating season, but applies the water through the entire year, running it over the land when and where he can in the winter as well as in the summer time. The land irrigated in the winter is covered from 1 to 2 feet deep. This land is not again irrigated during the year, and yields about three-fourths of a ton of native hay per acre.

For individual crops the time between the first and last application of water is sometimes very short. Where a crop is produced with a single irrigation the water may all be applied in one or two days, depending on the area and the method of running on the water, and where more than one irrigation is given only a few days may intervene. A few instances from actual practice will illustrate. The time between the first and last application of water to native hay on a ranch near Laramie in 1898 was ninety-four days. On the experiment station farm ninety-five days intervened between the first and last irrigation of alfalfa (which also represents the time from the first to the last irrigation on the entire farm), fifteen days with rye, from fourteen to sixty-nine days for different plats of oats, from nineteen to thirty-eight days with wheat, twenty-nine days with peas, fifty-one days with sugar beets, twenty-eight days with potatoes, and as few as thirteen days with barley. Such intervals of time represent the season during which application of water was made to the different crops. It will be noticed that the period varies greatly for the same kind of plants on different fields in the same summer. This variation may be influenced by such natural causes as rainfall, condition of the soil, and the length of time required for the variety being cultivated to reach maturity, but it is largely due to the opinion of the farmer as to when and how often applications of water are needed and to limitations in his ability to apply the water at a given time. Two fields may appear to need water on the same date, but two or three weeks may pass after beginning the irrigation of one before water can be turned on the other. The length of time between the first and second or between the second and third irrigations is equally uncertain, although with some crops, such as potatoes or fruits, the irrigations follow each other with great regularity, after having been begun. It seems to be the general opinion that for these crops the soil should not be allowed to dry out after the first irrigation till they have completed their growth and the time of ripening is reached.

SEASON OF USE AND OF GREATEST SUPPLY.

The relation of the water supply to the time of use is a most intimate one. Without reservoirs for storage the time of use is defined by the *flow in* the streams furnishing the supply. Fortunately, over a large

part of the arid region the streams on which irrigation depends have their sources in high snow-clad mountains and in forested areas at these high altitudes. These are the great natural reservoirs which furnish a practically perennial supply, and from which the maximum discharge occurs at the beginning of the growing season and occasionally approximately close to the time the largest amount is needed on the dry plains below. Where the streams are torrential in character as is usually the case if they head in barren uplands or in deforested mountain areas, the supply is uncertain and the time during which the flow continues is short. It often occurs that a stream has water in it for so brief a period that little use can be made of it for irrigation. In such cases storage is the only solution. With no means of holding the supply until it is needed the irrigating season is not long enough to mature a variety of crops, if, indeed, enough water can be obtained to mature any plants at all. To supply the crop the irrigator under such conditions must use the water when it comes, regardless of the then existing needs of the plants, and let the soil store up what it will. Much of the supply in the Southwest, including parts of New Mexico, Arizona, and Texas, comes from torrential streams, and the time of greatest flow is, unfortunately, not the time of greatest need. In the Dakotas and Kansas, where artesian and other wells are used for irrigation, the supply is continuous, but as a rule is so small that some means of storage is necessary in order to obtain a sufficient head to irrigate large areas. In the other irrigated States, including Colorado, Wyoming, Montana, and Utah, the main streams, as a rule, are perennial in character and the time of greatest supply is extended through a considerable portion of the growing season. In many instances streams which were once perennial have become torrential by the destruction of the forests over their catchment areas, and in all such cases the mountain storage of snow and ground water must be supplemented by artificial storage before the greatest development can be brought about.

Out of twenty-three answers made by ranchmen in different parts of Wyoming to the inquiry, "In what month do you need the largest amount of water?" thirteen replied that the greatest amount was needed in June, seven said their greatest need was in July, and the others stated that it was in July, August, and September. In general, the principal crop irrigated by those who need the largest amount in June is native hay, the use of water in other cases being largely for alfalfa, grain, vegetables, and fruit. The answers to the question, "In what month in the irrigating season do you use the smallest amount of water?" are equally divided between May, August, and September, while one stated that his smallest use was in October; and another, an excellent and most intelligent farmer, in northern Wyoming, stated that he used the least water in June and the most in July, on wheat, oats, alfalfa, and grass. The water measurements which

have been made give some definite information regarding the time of maximum use in the localities where they have been carried out. The following table and Plate VIII give in detail the amount of water used and the time of its use through the season for each crop upon which water measurements were made at Wheatland in 1893. To show the actual growing season of each crop, the dates planted and harvested are also reported.

The distribution of irrigation throughout the season at Wheatland, Wyo., 1893.

Crop.	Date planted.	Date irrigated	Water applied per acre at each irrigation.		Total water per acre.		Depth of irrigation and rainfall for season.	Date harvested.
			Quantity.	Depth over surface.	Quantity.	Depth over surface.		
			Cu. ft.	*Feet.*	*Cu. ft.*	*Feet.*	*Feet.*	
Alfalfa	June, 1891	Apr. 18	31,104	0.71	113,184	a2.60	2.86	July 5
		June 23	19,008	.44				Aug. 9
		July 12	14,256	.33				Sept. 16
		July 25	22,032	.51				
		Aug. 12	14,256	.33				
		Sept. 1	12,528	.29				
Barley, 3 varieties	Apr. 3	June 8	17,280	.40	39,744	.92	1.07	July 29
		June 20	12,528	.29				
		July 4	9,936	.23				
Corn, Minnesota King	May 12	July 3	12,096	.28	47,520	1.09	1.23	Sept. 24
		July 22	18,144	.42				
		Aug. 7	17,280	.40				
Flax (White Russian Belgian)	Apr. 28	June 14	34,560	.79	95,040	2.18	2.33	Aug. 8
		June 27	22,464	.52				
		July 8	38,016	.87				
Oats, Giant Side	Apr. 14	June 2	30,672	.70	76,896	1.77	1.92	Aug. 16
		June 9	15,984	.37				
		June 21	14,256	.33				
		July 4	15,984	.37				
Oats, Early Archangel	Apr. 15	June 5	19,008	.44	68,260	1.57	2.10	Aug. 29
		June 15	20,308	.47				
		July 5	21,168	.49				
		July 20	7,776	.18				
Potatoes, 22 varieties	May 15	June 21	9,072	.21	61,776	1.42	1.55	Oct. 16
		July 8	9,504	.22				
		July 18	7,776	.18				
		July 24	13,824	.32				
		Aug 4	10,368	.24				
		Aug. 17	11,232	.26				
Rye, spring	Mar. 29	June 5	22,896	.53	56,160	1.29	1.43	July 20
		June 19	21,600	.50				
		June 30	11,664	.27				
Rye, winter	Oct. 6, 1892	June 2	25,488	.59	38,448	.88	1.02	July 15
		June 17	12,960	.30				
Sugar beets, 4 varieties	May 4	June 17	31,104	.71	107,128	2.46	2.60	Aug. 6
		June 26	22,464	.52				
		July 8	15,552	.36				
		July 19	20,728	.48				
		July 31	17,280	.40				
Timothy	May, 1892	May 10	25,488	.59	102,384	2.35	2.48	July 22
		May 30	18,576	.43				
		June 19	20,304	.47				
		June 23	20,304	.47				
		June 28	17,712	.41				
Wheat, White Russian	Mar. 29	June 3	30,672	.70	69,984	1.61	1.76	Aug. 3
		June 17	15,984	.37				
		June 30	11,664	.27				
		July 7	11,664	.27				
Wheat, Fultz winter	Oct. 3, 1892	June 2	25,488	.59	41,040	.94	1.08	July 25
		June 17	15,552	.36				

a For the time between first and last irrigation, including .22 inches of rain. To the other figures in this column add 1.60 inches of rainfall for depth received by the land during entire year. Total rainfall for the year, 6.12 inches.

With annual crops planted in the spring the first irrigation occurs from one to two months after sowing the seed. Winter grain planted in the fall receives no water by irrigation till late the next spring, when enough is applied in one or two small irrigations to mature the crop. Hay crops may be irrigated as early as April or May, but as a rule irrigation of cultivated crops does not begin till June, or in some cases till as late as July. The table shows that the last irrigation usually occurs about a month before the time of harvest. Water stimulates growth, and it is found necessary to stop irrigating sufficiently early to allow the plants to properly mature before the time of frost. Grains are usually irrigated the last time when beginning to head out. This leaves sufficient moisture in the soil to insure plump grain and gives ample time for it to reach maturity. Where rusts prevail in the grain it has been found that keeping the soil wet after the plants reach full growth—i. e., after they are headed out—stimulates the development of such fungus diseases, but where water is kept away after the time of heading little difficulty has been experienced from rusts. It appears from the results given in the table that more water is supplied at the first irrigation than in later applications. This is probably due to the fact that the land is more porous, as it is nearer the time it was plowed, and also that the soil has become more effectually dried out than it is after once becoming compacted and thoroughly soaked at the time of the first irrigation.

Averages of the amount of water used at Wheatland during each month of 1893 for different crops[1] are given in the table below. In this table the measurements have been reduced to inches in order to make the differences more apparent than would be the case if stated in fractions of a foot.

Monthly distribution of irrigation water at Wheatland, Wyo.

[Depth in inches over surface irrigated.]

Month.	Alfalfa.	Timothy.	Corn.	Barley.	Oats.	Spring wheat.	Winter wheat.	Winter rye.	Flax.	Sugar beets.	Potatoes.	Total.
April	8.57											8.57
May		12.14										12.14
June	5.23	16.07		8.21	11.62	16.07	11.30	10.59	15.71	14.76	2.50	112.06
July	10		8.33	2.74	11.43	3.21			10.47	14.75	8.57	69.50
August	3.93		4.76		a2.12						5.95	16.76
September	3.45											3.43

a In 1889 only.

From this table it appears that the greatest amount of irrigation occurs in June for all crops except potatoes and alfalfa, which receive the most water in July, and it indicates that whether a farmer needs the most water in June or July depends on the kind of crop of which he has the largest area.

[1] The averages for oats and potatoes include measurements made by Territorial Engineer Mead in 1889.

The following table gives in detail the distribution of irrigation throughout the season at Laramie for the years 1895 to 1898, inclusive:

Distribution of irrigation throughout the season, Wyoming Experiment Station, Laramie, Wyo., 1895–1898.

Crop	Date planted.	Date irrigated.	Water used at each irrigation per acre. Quantity.	Water used at each irrigation per acre. Depth over surface.	Total water used for the season per acre. Quantity.	Total water used for the season per acre. Depth over surface.	Depth of irrigation and rainfall for the season.[a]	Date harvested.
1895.			*Cu. ft.*	*Feet.*	*Cu. ft.*	*Feet.*	*Feet.*	
All crops					50,266	1.154	1.829	
Potatoes	May 11	May 24, 25	11,683	0.27	11,683	.27	.944	Sept. 26.
Turnips and ruta bagas	May 14	May 27, 28	11,077	.25	112,733	2.59	3.264	Oct. 12.
		June 19	27,682	.64				
		July 6	17,622	.40				
		Aug. 17-19	56,352	1.29				
1896.								
Alfalfa	1894	June 17	24,556	.56	47,356	1.09	1.486	July 7 and Sept. 8.
		July 13	22,800	.52				
Barley (9 varieties)	April 23	June 29	19,749	.45	52,895	1.21	1.606	Aug. 14-28.
		July 24	33,146	.76				
Barley, oats, and wheat	May 5	July 2	41,216	.95	63,296	1.45	1.866	Sept. 12-14.
		July 27	22,080	.51				
Garden (furrow irrigated)		July 3-7	38,745	.89	54,270	1.25	1.666	
		July 30	15,525	.36				
Grain (furrow irrigated)	Apr. 20-21	July 2, 3	28,204	.65	61,122	1.40	1.786	
		July 22, 23	32,918	.76				
Potatoes		Aug. 8-14	13,866	.32	13,866	.32	.716	
Wheat (18 varieties) / Oats (3 varieties)	Apr. 4	June 20 to July 1	33,101	76	53,981	1.24	1.636	Aug. 29 to Sept. 10.
		July 23-25	20,880	48				
Wheat and oats (sod land)	May 8	July 31	41,886	96	41,886	.96	1.356	Sept. 25.
1897.								
Grain[b]	May 1	July 3-5	44,299	1.02	136,408	1.53	1.911	
		July 29	22,168	.51				
Oats, rye, barley, and flax	May 14	June 29, 30	41,265	.95	69,345	1.59	2.004	
		July 28	28,080	.64				
Peas	Apr. 21	June 26	20,093	.46	74,699	1.71	2.124	Oct. 4-6.
		July 30, 31	54,606	1.25				
Do	Apr. 27	July 1-2	96,916	2.22	136,408	3.13	3.544	Oct. 23.
		Aug. 2	39,492	.91				
Potatoes	June 8-12	July 31	19,475	.45	26,237	61	1.024	Oct. 2-9
		Aug. 16	6,762	.16				
Wheat (Blount No. 16) / Oats (Lincoln)	Apr. 21	June 25-28	70,560	1.62	107,012	2.46	2.874	Sept. 13-17.
		July 27	36,452	.84				
1898.								
Alfalfa (first year)	May 10-11	June 18-21	50,431	1.16	129,?88	2.97	3.353	July 15 and Sept. 7.
		July 20-22	36,938	.85				
		Aug. 30 to Sept. 3	17,525	40				
		Sept. 19-21	24,494	[illegible]				
Alfalfa	May, 1894	June 15-18	68,327	[illegible]	11?,101	[illegible]	2.983	July 14 and Sept. 8.
		July 1-6	24,710	[illegible]				
		July 23-25	10,355	[illegible]				
		Sept. 1, 2	3,617	.08				
		Sept. 15, 16	6,092	.11				
Barley, Highland Chief	Apr. 29	June 29	81,984	1.88	[illegible]	2.70	3.083	Aug. 30.
		July 11, 12	35,727	.82				
Do / Oats, Surprise / Wheat, Scotch or Scotch	Apr. 18 / Apr. 16 / Apr. 18	June 24	41,840	.96	[illegible]	[illegible]	2.102	Aug. 29. / Aug. 13. / Aug. 29.
		July 13	33,319	[illegible]				
Brome grass (first year)	May 14	June 29, 30	76,029	1.7?	[illegible]	[illegible]	[illegible]	
		July 15	35,290	.81				
		Sept. 1	18,392	.42				
Oats and vetch for hay	May 11	June 23, 24	39,919	.92	[illegible]	[illegible]	[illegible]	Aug. 3. Sept. —.
		July 15	17,046	.39				
		Aug. 31	11,788	.27				
Oats, Surprise	Apr. 20	June 22	36,207	.83	[illegible]	[illegible]	[illegible]	Aug. 16.
Oats, Bonanza	do	July 9-13	36,000	.83				
Oats, Lincoln	Apr. 23	Aug. 3	10,410	.24				Aug. 25.

a Add 3.06 inches (rainfall) for depth received by land during entire irrigation period in 1895, 6 inches in 1896, 7.02 inches in 1897, and 5.04 inches in 1898. The total rainfall for 1895 was 11.15 inches; 1896, 10.75 inches; 1897, 11.99 inches; 1898, 7.63 inches.

b Between 500 and 600 varieties of wheat, oats and barley planted in rows and irrigated in small furrows between.

Distribution of irrigation throughout the season, Wyoming Experiment Station, Laramie, Wyo., 1895-1898—Continued.

Crop.	Date planted.	Date irrigated.	Water used at each irrigation per acre. Quantity.	Water used at each irrigation per acre. Depth over surface.	Total water used for the season per acre. Quantity.	Total water used for the season per acre. Depth over surface.	Depth of irrigation and rainfall for the season.[a]	Date harvested.
1898.			*Cu. ft.*	*Feet.*	*Cu. ft.*	*Feet.*	*Feet.*	
Oats, Lincoln (on sod)	May 18	June 23 July 7 July 28	51,517 37,410 23,652	1.18 .86 .54	112,579	2.58	2.946	Sept. 3.
Oats, Surprise (on subsoiled land)	May 10	June 27 July 11	111,941 48,894	2.57 1.12	160,835	3.69	4.073	Aug. 17.
Peas	Apr. 16	June 28 July 8 July 27	72,179 32,640 19,490	1.66 .75 .45	124,309	2.86	3.243	Sept. 21.
Potatoes	May 11	July 7 July 28 Aug. 4	36,900 7,425 5,500	.85 .17 .13	49,825	1.15	1.533	Sept. 27.
Do	do	July 28 Aug. 4	7,425 5,500	.17 .13	12,925	.30	.683	Do.
Rye	Apr. 29	June 21 July 6	28,829 29,294	.66 .67	58,123	1.33	1.713	Aug. 13.
Sugar beets and rutabagas	May 24	July 7 Aug. 27	50,625 19,250	1.16 .44	69,875	1.60	1.983	Oct. 1.
Wheat, Blount No. 16 Oats, Lincoln	Apr. 16	June 25 July 14	35,280 40,573	.81 .93	75,853	1.74	2.123	Aug. 29. Aug. 18.
Wheat (5 varieties)	Apr. 18-22	June 25, 26 July 12 Aug. 2	74,485 34,846 48,670	1.71 .80 1.12	158,001	3.63	4.013	Aug. 19. Sept. 4.
Wheat, Surprise, and cultivated grain	May 10	June 27 July 11-14	54,460 13,017	1.25 .30	67,477	1.55	1.933	Aug. 17.

[a] Add 3.06 inches (rainfall) for depth received by land during entire irrigation period in 1895, 6 inches in 1896, 7.02 inches in 1897, and 3.04 inches in 1898. The total rainfall for 1895 was 11.15 inches; 1896, 10.75 inches; 1897, 11.99 inches; 1898, 7.63 inches.

From the table it appears that the season of use of water on the Laramie experiment farm is between the latter part of May and the last of September, or a total of about four months. From one to four irrigations are given the same crop, and almost without exception the first irrigation is heavier than later ones.

In 1898 measurements of the water used on a ranch on the Laramie plains showed that the most water was used in June and the least in September. The proprietor of this ranch supplied 52 acres with water, of which 43½ acres were native hay. He used 20.04 inches in June, 9.36 inches in July, 15.6 inches in August, and 0.0192 inch in September. Measurements at the Wyoming Experiment Station in 1895 show the following average amounts used in each month, including all crops:

Average amounts of irrigation water used on all crops during 1895.

	Inches.
May	0.31
June	5.84
July	2.87
August	1.63
September	2.30
October	.65

Enough water was used to cover all the land under cultivation to the depths given each month. In reality, all the land was not irrigated in any one month, and only a small fraction of it received water during any of the months except June. The crops were potatoes, turnips and ruta-bagas, wheat, oats, barley, rye, alfalfa, and general garden crops.

The average depth of water used each month on each crop at Laramie, so far as we have data, is given in the following table:

Average depth of water used each month on various crops at Laramie, Wyo.

Month.	Alfalfa.	Grass.	Peas.	Oats.	Barley.	Rye.	Wheat.	Sugar beets.	Potatoes.	Total.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	
June	13.16	20.50	19.92	15.21	13.16	7.92	13.71			103.58
July	8.72	9.51	20.52	9.85	11.40	8.04	10.64	13.92	8.82	88.45
August		10.32	10.92	1.86			[a] 13.34	5.28	2.44	42.16
September	7	.20								7.20
October	[b] 6									6

[a] One plat irrigated in August one year. In six other measurements on wheat it was irrigated in June and July only.
[b] This is an estimate of depth of water used one October to test the value of fall irrigation.

It will be noticed that the largest amounts were used in June on alfalfa, grass, oats, barley, and wheat. Peas, rye, sugar beets, and potatoes received the most water in July. Usually irrigation does not begin at the experiment station until the middle of June, and practically no water is used in September. A little fall irrigation may be done in October to keep alfalfa and fruits from drying out during the winter. Usually those who irrigate large tracts of hay land necessarily turn their water off by the middle of July in order to harvest the crops, and although the amount flowing in the river is so small at this time, it generally proves sufficient for those crops which need irrigating in the latter part of the season. This condition, however, would effectually prevent the farmers changing their present system of cropping to any great extent. Should everyone plow up his meadow, which needs the early supply of water, and plant potatoes, that need late water, the shortness of the irrigating season and its transference to the latter part of summer would at once produce water famine and restrict irrigation to a few early priorities, while others would go without. There must necessarily be some adjustment between the time of supply in streams and the time of necessary use in irrigation.

THE IRRIGATING SEASON IN LAW.

The water law in Wyoming provides that:

Each appropriation shall be determined in its priority and amount by the time by which it shall have been made and the amount of water which shall have been applied for beneficial purposes: *Provided*, That such appropriator shall at no time be entitled

to the use of more water than he can make beneficial application of on the lands for the benefit of which the appropriations may have been secured, and the amount of any appropriation made by reason of an enlargement of distributing works shall be determined in like manner: *Provided*, That no allotment shall exceed one cubic foot per second for each seventy acres of land for which said appropriation shall be made.[1]

Section 2, on duty of water, in the law for the Northwest Territories of Canada, reads as follows:

The duty of water, or the ratio between a given quantity of water and the amount of land it will irrigate, shall be one hundred acres for each cubic foot of water per second flowing constantly during the irrigating season, and division of the available water supply among applicants therefor shall be made upon the basis of this duty of water.

The Nebraska law covering the amount appropriated is an exact copy of the Wyoming law, and canal companies are required to furnish water from April 15 to November 1. In Colorado the law requires that beneficial use of the water shall be the basis on which allotments are made, and provides that ditch owners or companies who control water for pay must furnish a supply from April 1 to November 1 in each year.

In other places the amount of water which may be allotted an appropriator or the time it is to be furnished are not fixed. In Wyoming and Nebraska it is made the duty of the water commissioner to enforce economy in the use of water. The user is entitled to his full apportionment of 1 cubic foot for each 70 acres of land described in his certificate of appropriation during the time of minimum as well as maximum flow in the stream, provided he puts the water to beneficial use. In Canada, the term "irrigating season" is used but not defined.

CONTINUOUS FLOW AS A BASIS FOR APPROPRIATION.

Allowing a second-foot continuous flow for each 70 acres of land does not mean that the water is allowed to run continuously on the land for which it is appropriated. Only on native grass lands may a continuous flow for the season be used, and, as pointed out elsewhere, keeping the soil continuously saturated is bad practice. In actual use it is impossible to keep all the land wet all the time.

Flooding can not be done with much less than enough water to cover the land 3 inches deep, so that to flood 140 acres in twenty-four hours would require a head of over 18 second-feet. Under the most favorable conditions it is doubtful if an expert irrigator could flood 8 acres in twenty-four hours with a head of only 1 second-foot. On porous land which is dry a man would do well to thoroughly irrigate 1 or 2 acres a day. In irrigating small plats at the Wyoming Station consisting of from a fraction of an acre to 1 acre, a head of from 1 to over

[1] Session Laws of Wyoming, 1890–91, chap. 8, sec. 25.

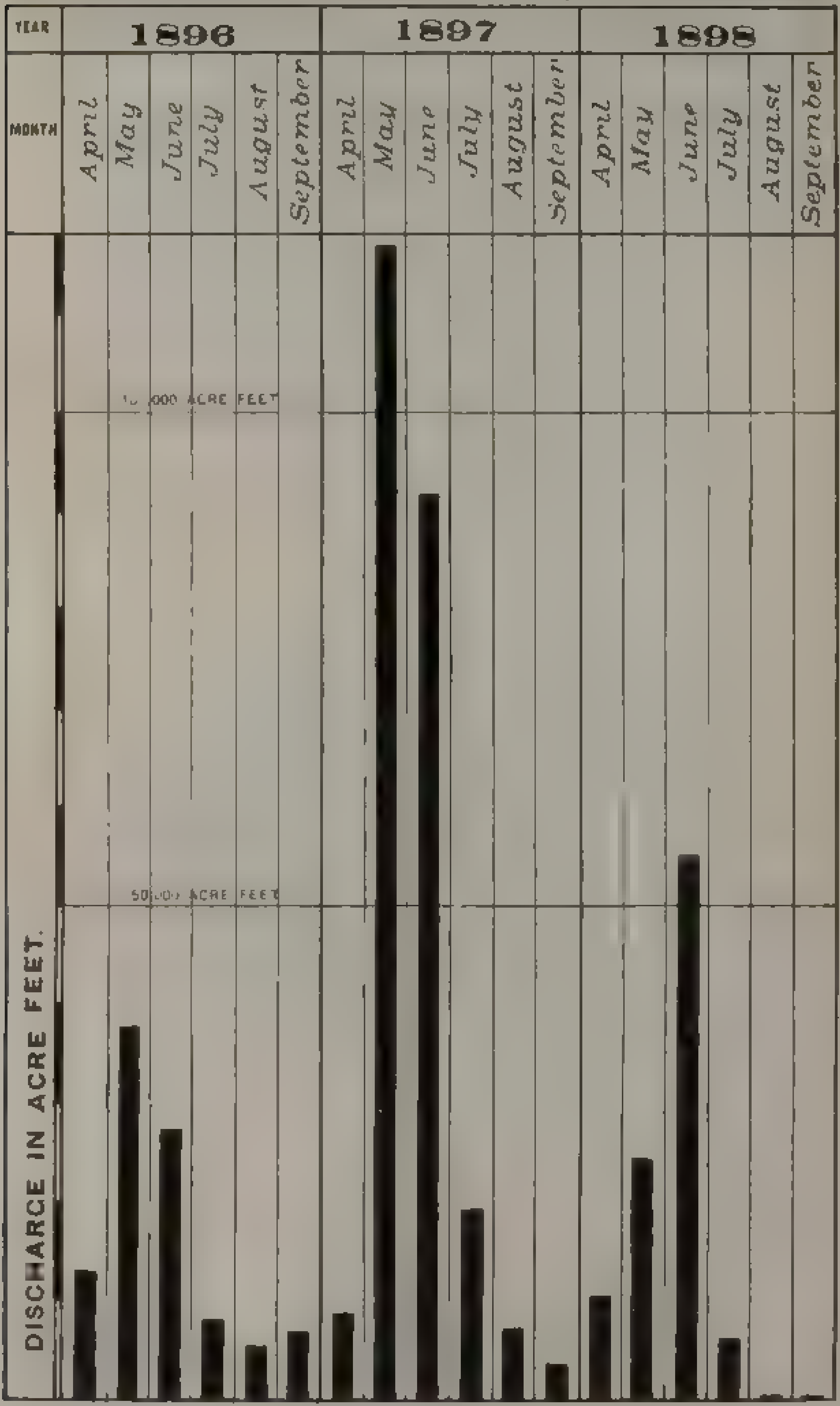
2 second-feet is ordinarily used, although it is sometimes as little as two or three tenths of a second-foot. Where the land is only partially irrigated, as with potatoes, by running the water in furrows, a very small head may sometimes be used; but in flooding sandy land little headway can be made with a flow of less than 2 or 3 second-feet. Irrigation is then necessarily intermittent, and in having a variety of crops, so that rotation in applying water can be practiced, the greatest use can be made of the supply.

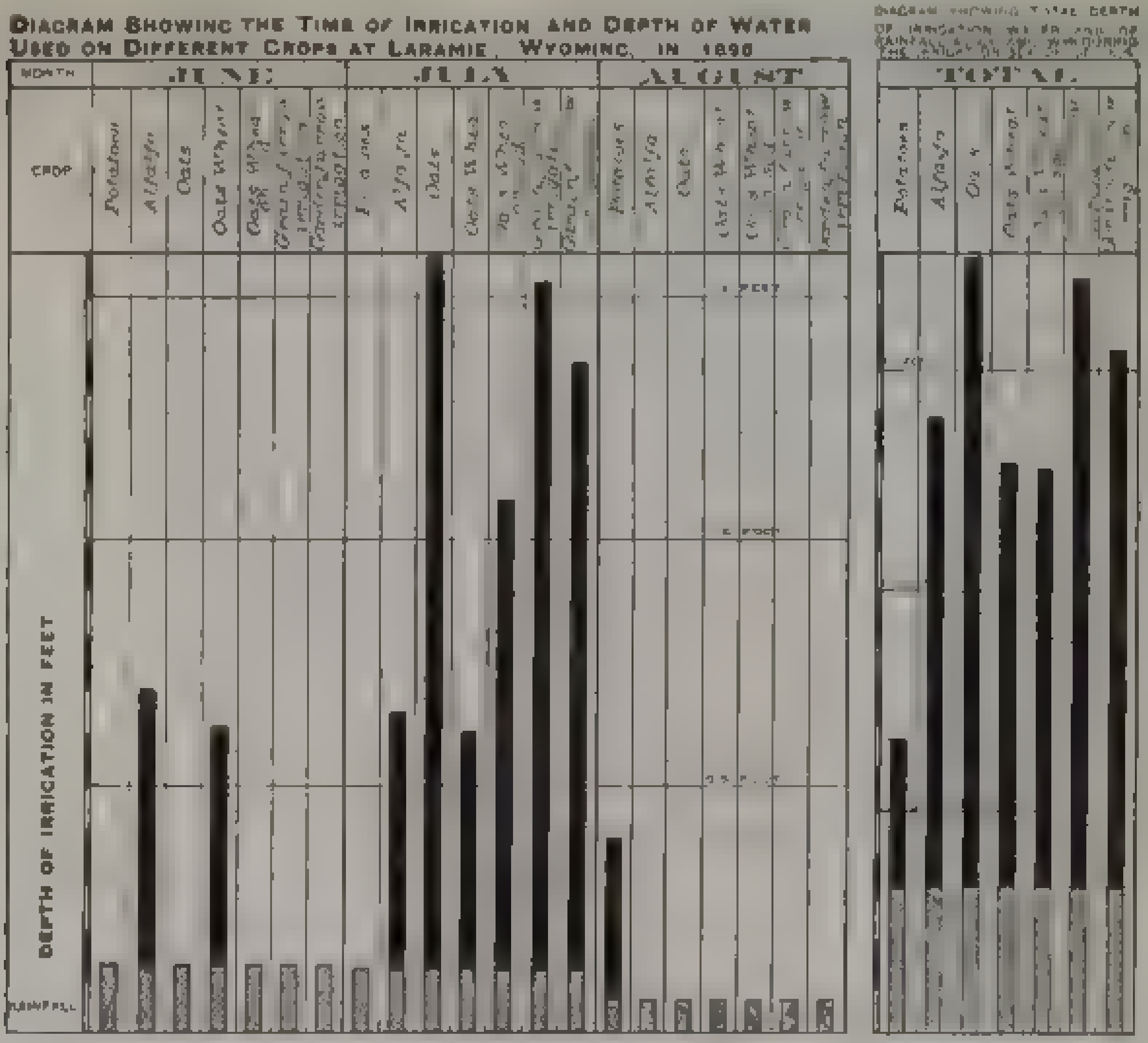
In making allotments to the users of water it would not be possible to limit the time during which continuous flow of a second-foot for each 70 or 100 acres is supplied to the time during which each crop actually receives water. For the purpose of raising crops, water can not be so used, and the amount of water obtained by the appropriator under this system must depend on some arbitrary length of the season.

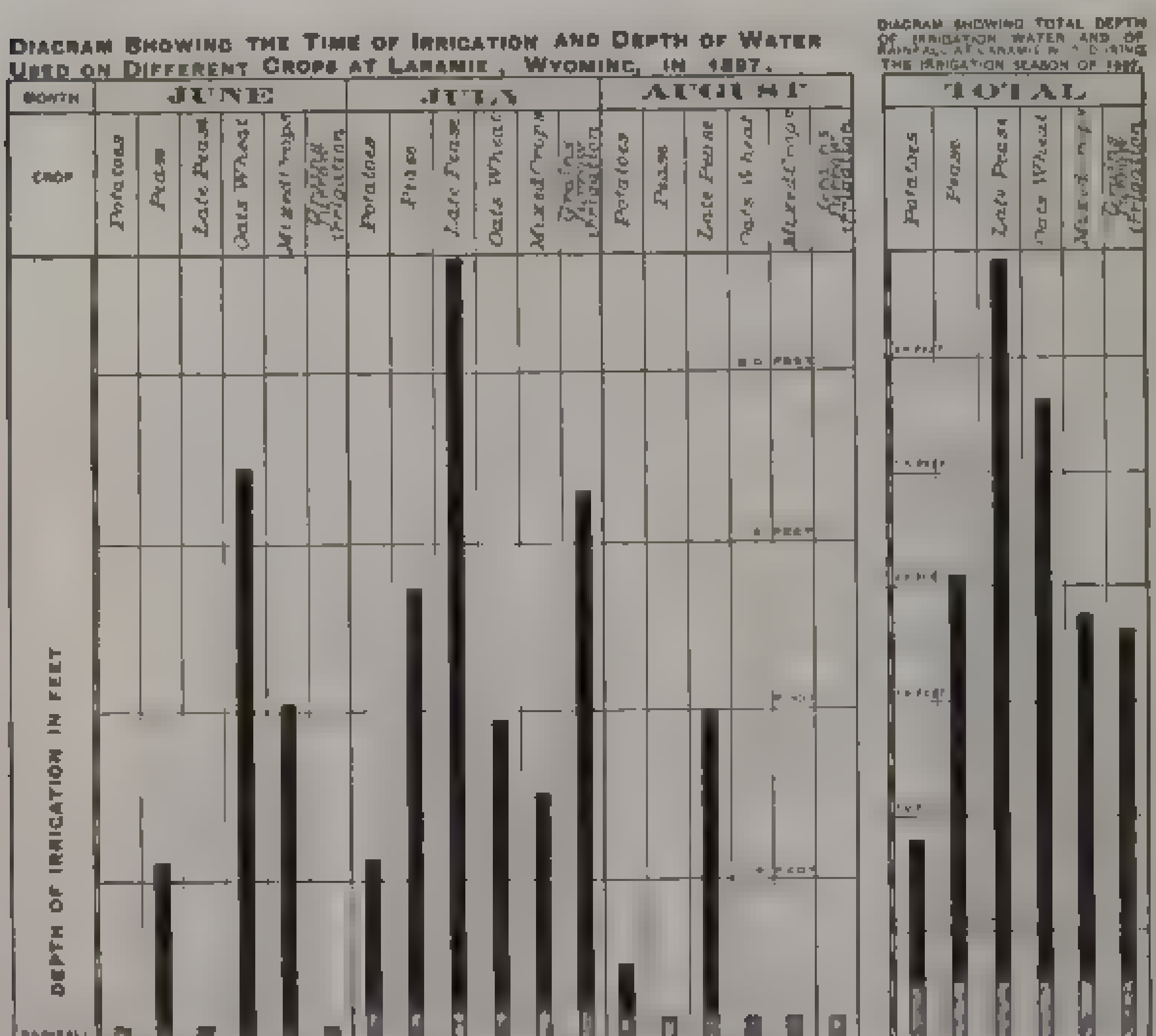
A cubic foot per second flowing continuously for ten days would cover 70 acres of land to a depth of 3.4 inches; flowing for fifty days it would cover the land 17 inches deep, in one hundred days 34 inches deep, and in a year 124 inches deep. The irrigator is clearly safe if he can define his own season and obtain in the few days his crops are to be supplied as much water for each 70 acres of land as a flow of 1 cubic foot per second for that season would furnish. He may need to use in less than fifteen days as much water on 70 acres of land as a cubic foot per second would supply in one hundred and thirty days. To do the irrigating in fifteen days would require a head of nearly 8.7 second-feet, flowing day and night. This illustration is taken from an actual case—that of oats on subsoiled land reported in the table giving water measurements on grain crops at Laramie in 1898. (See p. 33.) A little less than one-half acre of oats were irrigated twice, the irrigations being fourteen days apart. At the first irrigation the water flowed seven hours with a head of 2.01 feet, and at the second irrigation it flowed four and three-fourths hours with an average head of about 1.3 feet. The duty, allowing four months (May, June, July, and August), or one hundred and twenty-three days, for a continuous flow of 1 cubic foot per second, was 66.1 acres.

The Wyoming and Nebraska laws quoted at the beginning of this section are ingenious, and their application and value become apparent in connection with such a study as has been attempted here. The length of the irrigating season is not defined, leaving the amount of water which may be used by the appropriator sufficiently elastic to meet all requirements, though the irrigator would not be satisfied if it was necessary for him to attempt to irrigate so large an area with so small a head. Allotting water only for beneficial use on the land for which it is appropriated provides for the future reclamation of the greatest possible amount of the arid land with the available water supply. Future determinations of the facts relative to the beneficial

DIAGRAM SHOWING THE DISCHARGE OF THE LARAMIE RIVER AT WOODS LANDING, WYOMING, DURING THE IRRIGATION SEASONS OF 1896, 1897 AND 1898.







WATER USED ON VARIOUS CROPS AT WYOMING EXPERIMENT STATION, 1896 AND 1897.

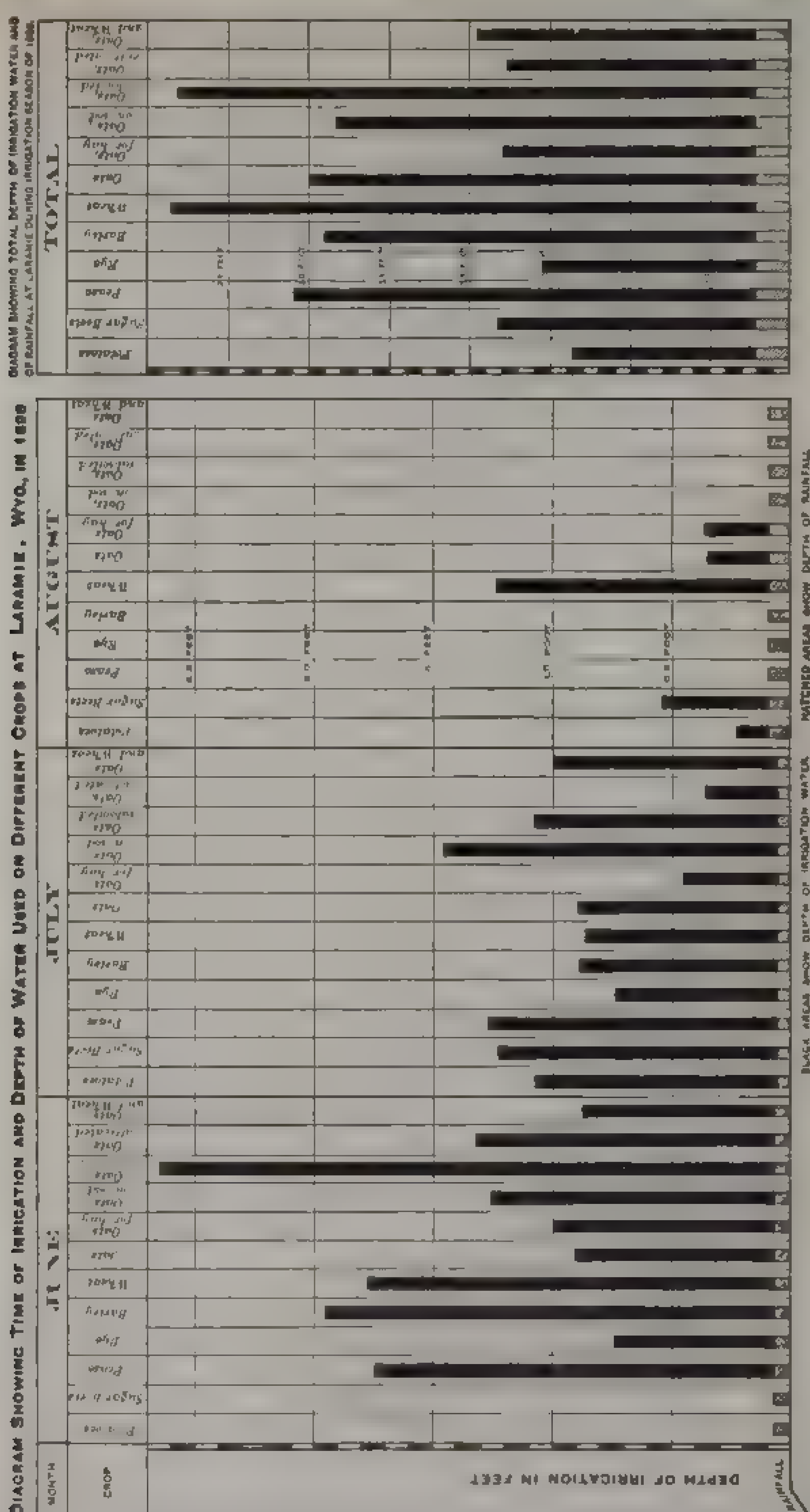


DIAGRAM SHOWING TIME OF IRRIGATION AND DEPTH OF WATER USED ON DIFFERENT CROPS AT LARAMIE, WYO., IN 1898
DIAGRAM SHOWING TOTAL DEPTH OF IRRIGATION WATER AND OF RAINFALL AT LARAMIE DURING IRRIGATION SEASON OF 1898.
MONTH
CROP
JUNE
JULY
AUGUST
TOTAL
Potatoes
Sugar Beets
Peas
Rye
Barley
Wheat
Oats
DEPTH OF IRRIGATION IN FEET
RAINFALL
BLACK AREAS SHOW DEPTH OF IRRIGATION WATER
HATCHED AREAS SHOW DEPTH OF RAINFALL

use of irrigation water can be applied without revision of the law, though it must be admitted that the present law does not cover the conditions actually obtaining in irrigation and that a continuous flow of 1 cubic foot per second for 70 acres of land may not be the best distribution of the supply.

A constant, uniform flow is a convenient method of dividing water from streams, but it is not an economical or satisfactory way of distributing from canals to users. Our supply is not available as a constant flow, and its use in irrigation is equally intermittent in quantity and time.

The actual instances of greatest supply at the time of greatest need or greatest use are undoubtedly rare, and the present method of appropriating an amount of water measured by a continuous flow for the land upon which it is to be used limits the amount of land which can be reclaimed to the supply in the stream at the time of its period of minimum flow during the irrigating season. If as much water is needed in July as in May, should five times as much water run down the streams in May its efficiency for irrigation purposes would not be greater than that measured by the July flow unless the water is stored till needed. Some years the Laramie River will supply enough water in May to irrigate 140,000 acres, allowing 1 cubic foot per second for 70 acres, while the supply in July would not be enough for 20,000 acres; consequently if the irrigator must have and can make beneficial use of his cubic foot per second for 70 acres in July, the natural flow of the Laramie River would not reclaim more than 20,000 acres.

In a recent publication Mr. Mead[1] says:

> There are two objections to making appropriations for irrigation a right to a perpetual flow of any definite volume of water. Such rights do not conform to the necessity of users or to the fluctuations in the flow of streams. No irrigator uses water all the time. In the States under consideration he does not use it one-half of the time. Even during the irrigating season the use is intermittent, and much greater in some months than in others. The holder of the right to a continuous flow, not needing it the greater part of the year, is continuously tempted to convert it into a speculative commodity by selling the surplus.

Reference to the tables on distribution of water throughout the season and to the accompanying charts will show the variations in the amount used each month and in the supply in streams, and represents an actual condition obtaining over a large part of the irrigated region. Plate V gives the supply furnished by the Laramie River in acre-feet for the years 1896, 1897, and 1898. There is a striking variation n the supply in different years, and the fluctuations in separate months during the irrigating season do not correspond with the necessities for crops. The maximum supply comes in May and the first half of June,

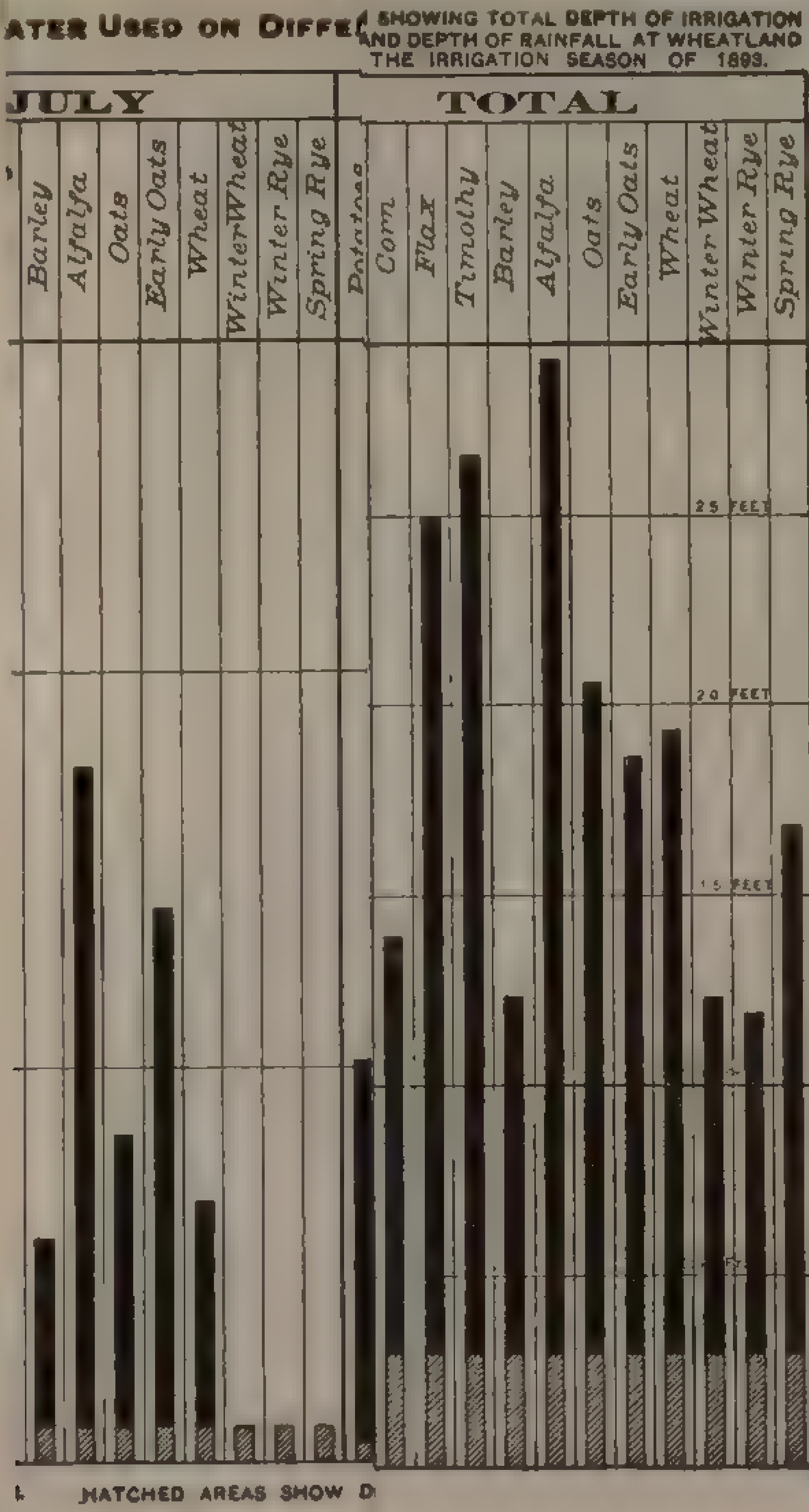
[1] Water Rights on the Missouri River and its Tributaries. U. S. Dept. Agr., Office of Experiment Stations Bul. 58.

when the largest amount of water is used on native hay, but the maximum irrigation of other crops comes later in the season. Plate VI, representing the irrigation of principal crops at Laramie in 1896, shows a maximum use of water in July for grain, and in August for potatoes. This and the following plates (VII and VIII) represent the depth of water in feet applied in irrigation, which also indicates the number of acre-feet actually used each month on each acre for the crops named. Then if oats needed a depth of water of 1½ feet in July, 1897, the discharge of about 28,000 acre-feet in the river for that month would be sufficient to irrigate 18,666 acres; and if four-tenths of an acre-foot was needed for potatoes in August, the discharge of the river of about 5,000 acre-feet for the same month would be sufficient to irrigate 12,500 acres of potatoes, providing none was used for other crops.

In 1897 the fluctuations in the supply were greater than in 1896. Compared with the amounts used in irrigation that year as given in Plate VI, there was enough water in June to irrigate about 54,000 acres of oats and wheat, or about 90,000 acres of mixed crops, while in July the supply had fallen to only about enough for 19,000 acres of oats and wheat or 28,500 acres of mixed crops.

In 1898, comparing the flow given in Plate V with the use by irrigation the same year given in Plate VII, the supply in June was sufficient to irrigate from about 21,000 to 62,000 acres of oats, depending on the condition of the soil; over 32,000 acres of peas or wheat, and about 18,000 acres of barley. In July the discharge of the river would only be sufficient for from 4,000 to about 18,000 acres of oats, about 4,800 acres of peas, about 7,000 acres of wheat or barley, or nearly 6,000 acres of potatoes. In August, 1898, the supply fell so low that it was no more than sufficient for 3,000 acres of potatoes or 1,000 acres of wheat.

This discussion simply shows that where continuous flow is made the basis of appropriations to users, the amount of land which can be irrigated is determined by the supply at the time of minimum flow in the season, and the few early priorities which have sufficient water at that time are the only ones who can mature crops which require water late in the season. Those who have later priorities can irrigate only in the early part of the season, when there is sufficient flow in the stream to supply every one, and must consequently irrigate such crops as will mature without the late water. The man who has the first right and receives the late water may not be the one who wishes to raise potatoes, alfalfa, or other crops which require water at that time, in which case he has something he neither needs nor wants, while his neighbor who raises such crops must have the water or meet with disaster. This gives rise to a temptation to separate the water from the land in order to speculate in it, to sell to the highest bidder, or to let a useful commodity go to waste. Growing a variety of crops


ATER USED ON DIFFE
SHOWING TOTAL DEPTH OF IRRIGATION
AND DEPTH OF RAINFALL AT WHEATLAND
THE IRRIGATION SEASON OF 1893.
JULY
Barley
Alfalfa
Oats
Early Oats
Wheat
Winter Wheat
Winter Rye
Spring Rye
Potatoes
TOTAL
Corn
Flax
Timothy
Barley
Alfalfa
Oats
Early Oats
Wheat
Winter Wheat
Winter Rye
Spring Rye
25 FEET
20 FEET
15 FEET
HATCHED AREAS SHOW D

lengthens out the irrigating season and enables the farmer to make better use of his continuous flow, but even this does not even up the difference between maximum supply and maximum use. The greatest necessity is storage until the water is needed. It would seem that the final solution must come through a system of storage combined with wise laws regarding appropriations which will insure the greatest use and economy of the whole water supply. The requirements of the land when used for the production of certain crops should be made the basis of allotments of water to users. There are in operation several ditch companies in the West which supply users with enough water in the season to cover their lands to a certain depth, and each farmer chooses the time through the season when each portion of the water is to be furnished. It would seem that such a system would eventually be followed by such adjustment of crops to the land and the water supply in different parts of the season as would bring about the greatest possible economy in the use of water.

GENERAL CONCLUSIONS.

In the region embraced in these studies the irrigation of native hay takes first place, both because it occupies the largest area of any single crop and because it is usually the first to be produced. There are several causes for this. It can be grown with less labor and expense than any other product, being already planted and requiring only irrigation and harvesting. It is one of the crops for which there is always an ample home market, the needs of the range stock business insuring this. It is furthermore a crop which is subject to few vicissitudes. Hail will not destroy it, and while a falling off in the water supply may greatly curtail the yield it will not result in an entire loss of the crop, as sometimes occurs with small grains and other cultivated products. The first attempt of the irrigator is usually, therefore, to make two blades of grass grow where one grew before. The growth of native hay, however, is the crudest and simplest form of irrigated agriculture. The return from the land is small and it is exceedingly wasteful of water. As both land and water become more valuable their use requires better methods and the growth of higher priced products. In the region under discussion irrigation is chiefly from small streams, and nearly all of the water supply which can be diverted is appropriated, but large volumes of water still run to waste in the larger rivers. It is along these that we must look for future development, but the utilization of this supply involves questions outside the scope of this investigation. These large rivers as a rule drain the mountain summits and have a more uniform flow than the small streams, as the snows which feed them melt slowly. The small streams, on the contrary, fluctuate so widely in

volume that it usually happens that more water runs to waste before irrigation of cultivated crops begins than is available for use in July, when the need for such crops is greatest. It is also an unfortunate circumstance that the most remunerative crops are those which require late irrigation. Sugar beets, potatoes, alfalfa, and orchards all require irrigation in August and September, which is the season of the least supply. These crops, while bringing large returns, require, as a rule, but little water, and their cultivation will secure a much higher average duty than now prevails; but to greatly extend the area of these products will involve comprehensive measures to increase through storage the present volume available for use in July, August, and September, because on three-fourths of the Wyoming streams there is now a scarcity in these months. If this shall not prove feasible, then the future extension of the areas now irrigated will come chiefly through the cultivation of crops which can be brought to maturity by water supplied before June 15. Among these, forage crops take first rank, as they can be irrigated as soon as water can be turned in ditches, and the stimulus given by a single watering will secure at least a partial crop. All these crops, however, are wasteful of water, and if they are to predominate in the extension of the reclaimed area, as will be necessary without storage, we may expect to see the average duty remain fully as low as at present.

The distinction between the abundant and hence cheap water supply of the first half of the irrigation season and the scanty and valuable supply in the latter half is made in appropriations and water-rights contracts in the irrigated districts of Europe, but as yet have not been considered in this State. We are not likely to continue to ignore this much longer. A second-foot of water for the month of August is worth ten to twenty times as much as the same volume for May, because it will make possible the irrigation of larger areas and the growing of high-priced products. It is this consideration which gives to water storage its significance and which will ultimately govern the number and cost of the works to provide for this purpose.

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FIG. 1.—THE HEADGATES OF AN IDAHO CANAL.

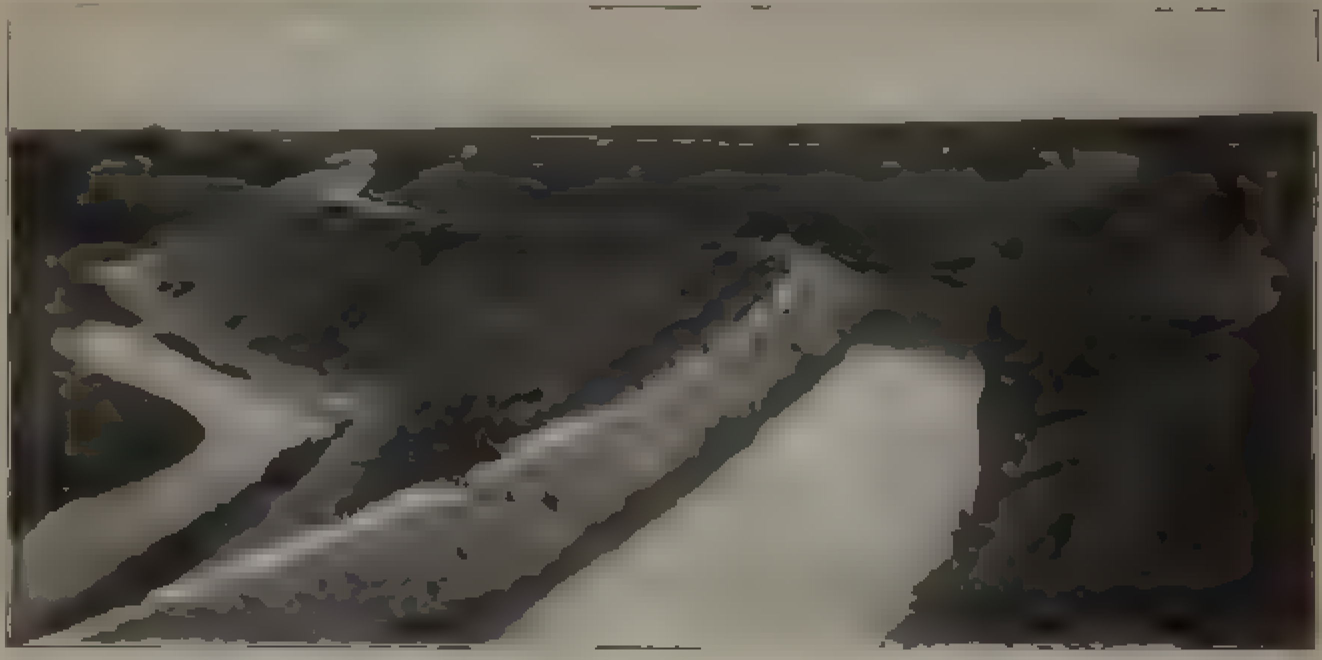

FIG. 2.—SIDE HILL CONSTRUCTION ON AN IDAHO CANAL.

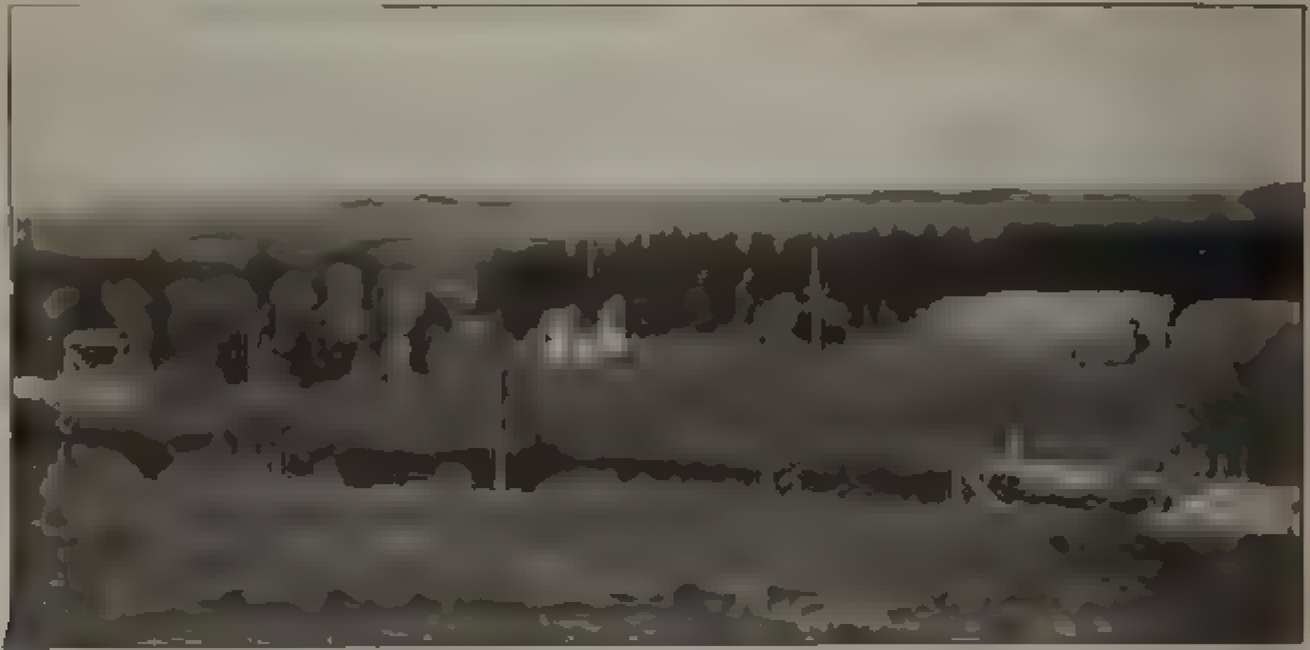

FIG. 3.—IRRIGATED FARM IN IDAHO.

BULLETIN No. 86. 356

U. S. DEPARTMENT OF AGRICULTURE,

OFFICE OF EXPERIMENT STATIONS,

A. C. TRUE, Director.

THE USE OF WATER IN IRRIGATION.

REPORT OF INVESTIGATIONS MADE IN 1899

UNDER THE SUPERVISION OF

ELWOOD MEAD, Expert in Charge,

AND

C. T. JOHNSTON, Assistant.

INCLUDING REPORTS BY SPECIAL AGENTS AND OBSERVERS W. M. REED, W. H. CODE, W IRVING, O. V P STOUT, THOMAS BERRY, S. FORTIER, R. C. GEMMELL, G. L. SWENDSEN, AND D. W. ROSS.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1900.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., June 9, 1900.

SIR: I have the honor to transmit herewith a report of investigations on the use of water in irrigation made in 1899 under the supervision of Mr. Elwood Mead, expert in charge of irrigation investigations, and C. T. Johnston, assistant, and to recommend its publication as a bulletin of this Office.

These investigations were carried out in pursuance of the original plan and purpose of the Office to confine its work on irrigation mainly to two general lines: "(1) The collation and publication of information regarding the laws and institutions of the irrigated region in their relation to agriculture, and (2) the publication of available information regarding the use of irrigation waters in agriculture as shown by actual experience of farmers and by experimental investigations." Several bulletins bearing on the first phase of this subject have already been issued. The present bulletin deals primarily with the second. It records the results of observations on the duty of water in ten States and Territories of the arid region, namely: Texas, New Mexico, Arizona, California, Nebraska, Colorado, Wyoming, Montana, Utah, and Idaho.

The determination of the duty of water in irrigation was made a leading subject of these investigations, because it is believed that a more general understanding of the causes which increase or diminish the duty of water is one of the most urgent needs of agriculture in the irrigated region. Discussing the results obtained in the investigations reported in this bulletin, Mr. Mead says: "A comparison of the duties secured under many of the canals where measurements were made last year leads to the belief that it will be possible through improved methods to double the average duty now obtained, so that the quantity now required for one acre will serve to irrigate two. If this can be accomplished it will relieve the scarcity under many canals, put an end to many controversies growing out of such scarcity, lessen the expense per acre for water, and immensely increase the productive and taxable resources of the arid States."

Respectfully,

A. C. TRUE,
Director.

Hon. JAMES WILSON,
Secretary of Agriculture.

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THE USE OF WATER IN IRRIGATION.

DISCUSSION OF INVESTIGATIONS.

By Elwood Mead,
Expert in Charge of Irrigation Investigations.

INTRODUCTION.

The investigations described in this report deal with problems which perplex the irrigators and canal builders of the arid West, and which, for the last ten years, have been constantly growing more important. Their comprehensive study is a new feature of national aid to irrigation development in this country. Heretofore the leading object of such aid has been to promote the construction of new canals, to show how much of the land above existing ditches could be reclaimed, and the benefits which would come from such reclamation. It is believed that this investigation will also tend to secure these ends, but its primary purpose is to assist the cultivators under ditches already built, to render the farms now irrigated more profitable, to lessen the controversies over the distribution of water, and to secure its more systematic and economical use.

It is the opinion of those best informed that a better understanding of the existing situation must be had before we can wisely plan for future development. Controversies exist over the partial use of streams. These should be ended before an attempt is made to greatly augment such use. The claims to water for existing and prospective ditches on many streams amount in the aggregate to many times the supply. These rights are now vested, and their character must influence what is to be done in the future.

When irrigation first began, little attention was paid to the economical use of water or to the just division of rivers among irrigators. The area watered was so small that the owners of ditches did not need to consider how much was used or how much was wasted. They had all they wanted, and because it cost nothing and they were free to take it as they pleased they failed to realize its coming scarcity and importance. Every transaction which had to do with the disposal of

streams was marked by a lavish prodigality. Ditches diverted more water than was used. Their owners claimed more than they could divert, while decrees gave appropriators titles to more water than ditches could carry and many times what the highest flood could supply. Little was known of the quantity of water needed to irrigate an acre of land, and in the absence of such information the ignorance and greed of the speculative appropriator had its opportunity.

In many cases the contracts which control the distribution of water from canals have been framed by people to whom the whole subject of irrigation was strange and new. It often happens, therefore, that these contracts do not promote the best interests of canal companies or meet the necessities of users. The laws which govern appropriations of water from streams have, in most cases, no relation to the actual practice of irrigators, and therefore fail to secure either the systematic distribution or best use of the available supply. As illustrating how little was formerly known of the actual necessities of irrigators, the contract of one canal company provides for delivering 1 cubic foot of water per second to 54 acres of land. In five months this would cover the land 5½ feet deep. Another canal contract provides for furnishing 1 inch to each acre. The laws of the State where this occurred make 40 inches equivalent to 1 cubic foot per second; hence, in an irrigation season of one hundred and fifty days this would involve the delivery of enough water to cover the area irrigated to a depth of 7½ feet. Another contract provides for furnishing 43,560 cubic feet for each acre irrigated, or enough to cover the land to a depth of 1 foot. The headgates of these three canals are only a few miles apart. They take water from the same stream and supply farms practically alike in every respect, yet the first contract provides for supplying 5½ times as much as the third and the second one 7½ times as much. In widely separated localities the difference is much more marked. The water-right contracts examined fix the duty of an "inch" of water anywhere from 1 to 10 acres, the lowest duty being found in sections where water is not used more than three months in the year, and the highest in California, where little rain falls and where the use of water is practically continuous.

The irrigated district watered by the Poudre River of Colorado is not surpassed by any other in either the intelligence of its irrigators or the excellence of the methods employed in the distribution of water from the stream. This high standing had already been established when the adjudication of its waters took place. The results, therefore, can be fairly taken as representing the best rather than the worst of the original conceptions of farmers and irrigation officials as to the actual necessities of irrigation. When this adjudication took place there were 23 early ditches which, taken together, irrigated about

1,000 acres of land.[1] These ditches were small and could not do more than irrigate the bottom lands along the stream, yet their combined appropriations as fixed by the decree amounted to 692 cubic feet per second, or enough water to have irrigated 41,520 acres on a duty of 60 acres per cubic foot per second, or more than 40 times the water actually used under wasteful methods, and more than 100 times the water actually needed under the methods now prevailing on that stream. From the report of the State engineer of Colorado for 1889-90, we find that the mean annual flow of the Poudre River in the first of these years was 735 cubic feet per second; in the second, 770 cubic feet per second, and that this volume of water served to irrigate 139,000 acres of land. This was a duty of 189 acres for each cubic foot per second in 1889, and 180 acres in 1890. The adjudication therefore gave to 1,000 acres of land almost as much water as serves to irrigate nearly 140,000 acres. The State engineer's report for 1898 states that in September of that year the discharge of the river was only 100 cubic feet per second, while in October it was 35 cubic feet per second.

Boyd's history of Greeley and the Union Colony gives additional illustrations of the extravagant rights which have grown out of a lack of knowledge of the actual necessities of irrigation. From it is taken the following extract:

> As instances of the excessive quantity of water awarded ditches under the decree, compared with the crops cultivated under them, we may take the Boyd and Freeman ditch, which has 99.38 cubic feet awarded to it in 1873, while the crops under it in 1888, said to be irrigated, were 320 acres, which is, I believe, all the land under the ditch owned by its proprietors. This would be a duty of less than 4 acres to the cubic foot per second. Again we may take the B. H. Eaton ditch, which was awarded for 1872, 41 cubic feet per second, and had in irrigated crops, 1888, 330 acres, or a duty of 8 acres per cubic foot per second. The John Coy ditch is credited with 31 feet and irrigated in same years 160 acres, or has a duty of about 5 acres per foot.[2]

In another State enough water was awarded to one man in 100 days to submerge his farm under a body of water 23 feet deep, while across a boundary fence his neighbor was given only enough to cover his land to a depth of 1.5 feet, the scarcity in one case being as injurious as the excess in the other.

SOCIAL AND INDUSTRIAL FEATURES OF IRRIGATION.

Before the period of crude structures and still cruder ideas had ended, it began to be manifest that the reclamation of arid lands involved more than the overcoming of physical obstacles. It has been found easier to dig ditches than to distribute the water they carry, and to plan headgates and flumes than to frame just laws for establishing titles to water or dividing rivers among rival claimants.

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[1] History of Greeley and the Union Colony, by David Boyd, pp. 124, 125.
[2] Pages 125, 126.

The reason for this is found in the overshadowing importance of water. Wherever irrigation is required, water rather than land controls development. It is easy to realize this when it is remembered that in arid lands not a flower will bloom, not a tree bear fruit, nor a field bring forth its harvest unless water is supplied by the skill and industry of man; hence, as the reclaimed area has extended and the number of homes dependent on irrigation has been multiplied, the collection, sale, and distribution of water has grown to be a stupendous industry, in which many millions of dollars (estimates vary between $100,000,000 and $200,000,000) are invested.

The many thousands of miles of canals and laterals in the irrigated regions of the United States have reclaimed an area approximately as great as the State of New York, every acre and almost every square foot of which has to be artificially moistened from one to ten times each year. During the growing season this requires the services of an army of men to protect and regulate headgates, patrol the banks of canals, and adjust the measuring boxes of users.

The success or failure of these canals is a matter of more than local interest. Much of the money expended in their construction came from the East. The savings of thousands of thrifty New England people have been invested in stocks and bonds of irrigation companies, a single agency in Colorado having invested $15,000,000 in this class of securities for these customers. The failure of a canal company to find customers for water, or to supply water to the customers it has, affects many others besides the immediate parties to these transactions. Theirs is the immediate loss, but sooner or later this loss also shows itself in delayed or defaulted interest payments, and this affects the holder of the stock or bonds of the canal company. The justice and efficiency with which streams are divided and the economy with which water is used may, therefore, in this way augment or reduce the incomes of many Eastern as well as Western homes.

DISTRIBUTION OF WATER AMONG USERS.

Traffic in water is carried on under many peculiar and perplexing conditions. No matter from what source the supply is received, whether it is stored in reservoirs, pumped from wells, or taken from rivers, the distribution of water in irrigation is subject to unending uncertainties. Streams rise and fall with every passing cloud: the torrent of to-day may be a dry channel a month hence; wells which can not be exhausted in April are often empty in June. Even after water has passed the headgate and is safe from outside interference the waste and loss continue. It disappears through the bottom of the canal by seepage, and into the air by evaporation. The same vicissitude attends its use. As much water may escape from the lower side

of the field of a careless irrigator as sinks into the soil. The waste from badly built laterals or poorly prepared fields does much to limit the area which a canal can serve, and hence the income it can be made to yield.

This commerce in water has been created by men born and reared in regions of ample rainfall and without prior training or experience in dealing with the problems of irrigation. They had to learn by trial how to frame satisfactory contracts for the disposal of water from canals and how to use that water properly when delivered. From the construction of the first small furrows in Utah and California up to the present the growth in acres irrigated has been accompanied by an equally important evolution in methods. The fixing of a unit of measure to be employed in delivering water to users will serve to illustrate this. It could not be sold by the pound or by the ton, nor were there any devices at hand for its measurement or delivery by the gallon. Farmers were at a loss to know how much to buy and canal companies as ignorant of how much they could sell or how to measure it when sold.

UNITS OF VOLUME EMPLOYED IN MEASURING WATER.

THE INCH.

In a number of the arid States placer mining was an important industry before irrigation began. Miners in measuring water employed the "inch." This is the volume which will flow through an inch-square orifice under a uniform and designated pressure. Later, the pressure to be employed and the manner in which the size of the orifice was to be increased or diminished was, in a number of States, fixed by law.[1]

In those sections where irrigation succeeded this form of mining, irrigators generally adopted this unit. In many respects it is entirely satisfactory. Where the flow is controlled by a device of reasonable accuracy it is a convenient method of delivery for canal companies and satisfactory to users, because they can tell at a glance whether or not the quantity contracted for is being delivered. It is not suited, however, to the measurement of rivers, or to the regulation of their division among large canals, as the prescribed conditions can not be

[1] Water sold by the inch by any individual or corporation shall be measured as follows, to wit: Every inch shall be considered equal to an inch-square orifice under a five-inch pressure, and a five-inch pressure shall be from the top of the orifice of the box put into the banks of the ditch to the surface of the water. Said boxes or any slot or aperture through which such water shall be measured shall in all cases be six inches perpendicular, inside measurement, except boxes delivering less than twelve inches, which may be square, with or without slides. All slides for the same shall move horizontally, and not otherwise, and said box put into the banks of ditch shall have a descending grade from the water in ditch of not less than one-eighth of an inch *to the foot*. (General Statutes of Colorado, sec. 3472.)

produced on a large stream of water. There are canals which carry 12,000 inches. To measure this volume under the conditions prescribed in the Colorado statute would require a slide so long and heavy that its use would be practically impossible. The use of the term "inch" has also been unfortunate. Many farmers have confused this expression with the surface or the cubic unit of the same name, and it frequently happens that the inches of water in use are determined by measuring the cross section of a ditch or lateral and paying no attention whatever to either grade or velocity. In one case a State law confuses cubic inches with the continuous flow from an inch-square orifice.

THE CUBIC FOOT PER SECOND.

The cubic foot per second is a definite and convenient unit of volume to employ in the gaging and division of rivers and in measuring the discharge of ditches and canals. A majority of the arid States and Territories have made it the legal unit in fixing the volume in water-right contracts between canal companies and irrigators and in defining the amounts of appropriations from streams. This unit has the double advantage of showing precisely what is meant and being well adapted to the measurement of large as well as small volumes of flowing water. It is the most satisfactory unit which can be employed in dividing rivers or in measurements where the flow is continuous. There is, however, an objection to its universal use. Where decrees or contracts provide for the delivery of a continuous flow it is presupposed that irrigators use water in this manner. This is not in accord with the best practice. Irrigators do not need water all the time. Few use it half the time. If they are required to pay for a continuous flow, they usually pay for something they do not get, and always for what they do not need. The best practice provides for rotation on the part of irrigators in the use of water and the use of a larger volume of water for only a part of the time. Where this occurs, a different unit of measurement is desirable, because it is not the continuous delivery of a stream of a designated size which is paid for, but the total volume furnished during the whole or any part of the irrigation season.

THE ACRE-FOOT.

The growing recognition of the fact that a continuous flow of water does not correspond to the needs of irrigators has recently brought into use another unit of volume—the acre-foot. It contains 43,560 cubic feet, or enough to cover an acre 1 foot deep. It is a convenient unit for selling stored water, since the capacity of reservoirs can be measured by the same unit.

Contracts in which the acre-foot is used provide for the delivery of water on the demand of the irrigator, or at intervals rather than in continuous flow, and canal companies have hestitated about adopting this unit because of a fear that satisfactory arrangements for delivery could not be made, but that more water would be called for at some time than the canal could supply, while at other times the entire volume would run to waste.

Wherever the acre-foot has been adopted it has proved acceptable to irrigators, because they share in the benefit resulting from care and skill in distribution.

FORM OF WATER CONTRACTS AND BENEFITS OF ROTATION.

The contracts between canal companies and irrigators take various forms. Some purport to be deeds to water; others are contracts for a perpetual right to water for a designated tract of land; others provide for payment of an annual rental for the area irrigated, to be renewed each year; while an increasing number provides for the measurement of and payment for the quantity delivered. Formerly the difference in conditions prescribed was much greater than at present, the tendency now being to follow precedent and copy the forms which have worked well in practice.

Contracts which provide for the delivery of a uniform constant flow are, as a rule, wasteful of water. They are not, therefore, to the interests of either ditch companies or the public. Contracts which charge for the acres irrigated, without regard to the volume used on these acres, are a temptation to extravagance on the part of the irrigator. The canal company which employs such contracts resembles the grocer who would agree to supply his customers with a year's provisions at so much per head, with no restrictions as to quantity or kind of goods which might be called for. On the other hand, contracts providing for payment proportioned to the quantity delivered and for its delivery in amounts which can be most efficiently distributed can not fail to lead to great economy in the use of water and consequently to a high duty, as the irrigator pays for what he wastes and also gets the benefit of his saving. Such contracts can be employed only in connection with a system of rotation in delivery to irrigators. This rotation benefits the canal company as much as the irrigator, because it lessens the loss from evaporation and seepage in the following manner: If a canal is large enough to supply 100 farms it will still supply them whether they are all irrigated every day or one-half given twice the usual supply every other day. On large canals the economy of such rotation is very great. It would permit of dividing them into sections and supplying the lands under one section at a time. A canal 60 miles long could be divided into three sections

of 20 miles each and all the loss from seepage and evaporation on the lower 40 miles saved while the irrigators of the upper section were being supplied. In the same way, by keeping the full supply in the canal, water could be rushed through to users under the lower section with less loss than where the flow is depleted by laterals along the route. The geatest saving in rotation, however, would be made in laterals. The most wasteful system possible is where water is permitted to slowly dribble through these all the time. The engineer of a canal, by devising a system for dividing laterals into groups and inducing the irrigators therefrom to take water by turns, can do as much toward raising the duty obtained as can the actual cultivator. The use of a unit which favors rotation will also lead to rotation in the division of a river between canals. There is great waste in running the canals half full all the time, as the absolute loss from seepage and evaporation is nearly the same whether the canals are full or only half full. It would be far better when rivers are low to run half the canals at a time and provide them with a full supply, thus saving nearly half the water ordinarily lost in transit. As the loss from seepage and evaporation averages about 30 per cent of the water flowing in canals, the water saved will be a material addition to the available supply.

INVESTIGATIONS IN 1899.

REASONS FOR INVESTIGATION OF THE DUTY OF WATER.

As the water required to irrigate 1 acre of land should be the basis for fixing the dimensions of works required to irrigate any number of acres, there is need to know approximately its amount. In order to plan for the just distribution of the volume entering the headgate, the losses in transit must be provided for. Until more is known than is now known about the time of year when the irrigation season begins and when it ends, the part of the discharge of any stream which must run to waste unless stored can not be estimated. Until it is known how large an area an acre-foot of stored water will irrigate and the returns which will come from such irrigation, the value of reservoirs will have no more substantial basis than individual judgment or conjecture, nor can an intelligent estimate be made of the amount of money which can be profitably spent in their construction. Sooner or later a knowledge of the duty of water becomes a necessity in any irrigated district. It is now urgently needed to settle disputes over water-right contracts, and to provide for their intelligent reconstruction. Thus far it has been the uniform practice to make all rights to water perpetual and continuous. This is not the practice of European countries. Italy, France, and Spain each distinguishes clearly between rights to the summer and to the winter flow, the vernal and autumnal

equinoxes being the dates when one begins and the other ends. The controversies which have recently arisen over rights to the winter flow of streams will doubtless soon lead to a similar distinction in Western irrigation laws. A comparison of the duties secured under many of the canals where measurements were made last year leads to the belief that it will be possible through improved methods to double the average duty now obtained, so that the quantity now required for 1 acre will serve to irrigate 2. If this can be accomplished, it will relieve the scarcity under many canals, put an end to many controversies growing out of such scarcity, lessen the expense per acre for water, and immensely increase the productive and taxable resources of the arid States.

Believing that a more general understanding of the causes which increase or diminish the duty of water is one of the most urgent needs of agriculture by irrigation, the determination of this duty was made a leading subject of these investigations.

METHODS EMPLOYED IN THE INVESTIGATION.

In carrying out this investigation laboratory methods will not answer; it must deal with the use of water on a large scale. The work requires the supervision of men of special training and wide practical experience. One of the chief difficulties encountered at the outset was to find the right men to take charge. Those engaged are, without exception, holding positions of responsibility and receiving ample compensation from other sources; the chief inducement for their taking part in this investigation has been the promotion of the public welfare. Through their interest and zeal this report includes a large amount of information which could not otherwise have been secured for ten times the actual outlay. It was left for the observers in each State to secure the cooperation of intelligent, practical farmers and to arrange with them to measure the water used on their fields. In nearly every case this was easily accomplished. Every farmer connected with the investigation received the same instruction. It was to use water whenever and wherever it was thought necessary, provided it could be had, and pay no attention to the fact that it was being measured. The results show that this was done. The descriptions of canal systems and the methods which govern their operation given in the reports of the special agents show how direct is the relation between good management and a high duty of water. They also show how prolific of waste and loss is a badly drawn water-right contract. Records were also kept of rainfall and evaporation; and an effort was made in each case to secure as much information as possible on the following factors of the duty of water in irrigation:

The quantity of water required by different crops.

The length of the irrigation period in different sections of the arid region.

The agreement or divergence between the quantity of water used in irrigation in the different months of the growing season and the rise and fall of streams during those months.

The benefits of reservoirs and the percentage of the total discharge of streams which must be stored in order to utilize the whole supply.

Losses in canals from seepage and evaporation.

Influence of different forms of water-right contracts in promoting economy or waste.

The returns from the use in irrigation of an acre-foot of water.

INSTRUMENTS EMPLOYED IN RECORDING AMOUNTS OF WATER USED.

In these studies an instrument was needed which would keep a continuous and automatic record of the quantity used. The quantity

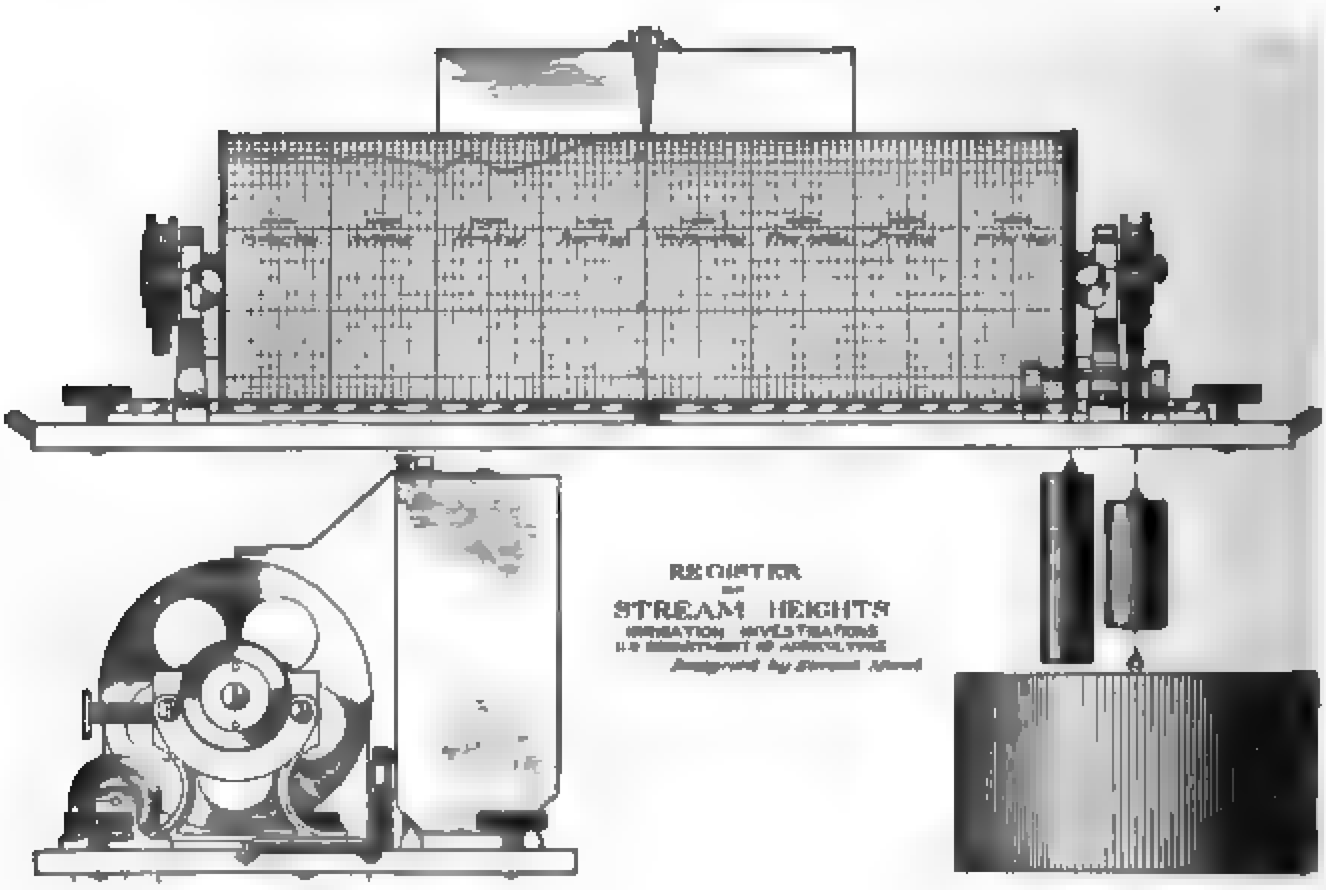


FIG. 1.—Water register No. 1.

received by each irrigator fluctuates with the flow in the main canal and with his own and his neighbors' demands on their lateral. Finding it impossible to employ a meter to measure the volume delivered, it was decided to place a weir or flume in each canal or lateral, and then by means of a suitable instrument keep a continuous record of the depth of water delivered. Wherever possible weirs were used, but in more than one-half of the cases where they were used the results proved that flumes would have been more satisfactory.

A study of the registers in use showed that none were wholly satis-

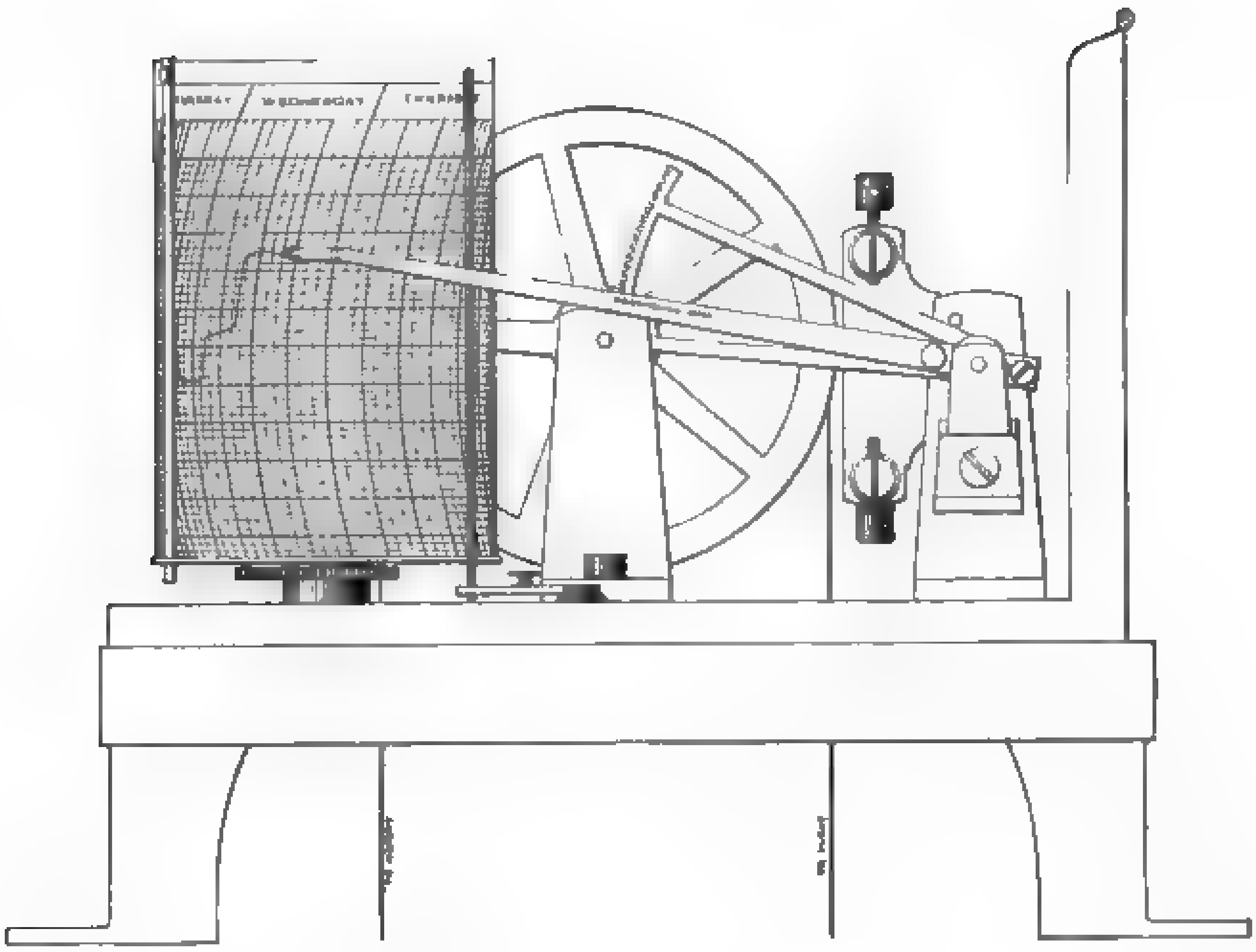


Fig. 2.—Richard Brothers' water register

factory. The first requisite was a record on a natural scale, so that an inch rise or fall in the ditch would be so shown on the record sheets, thus enabling any farmer or ditch rider to determine at a glance whether or not the instrument was working accurately, and if not to correct it without the computation required where the scale is reduced. Not being able to obtain registers of this pattern, one was designed. Its form is shown in the accompanying drawing of register No. 1 (fig. 1).

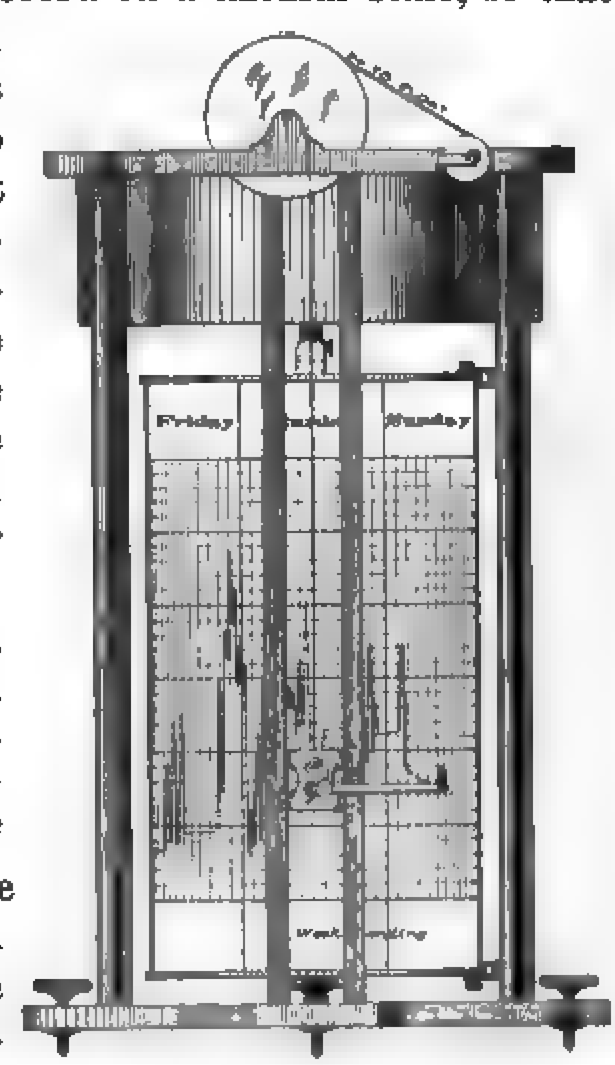


Fig. 3.—The Wyoming nilometer

In this instrument the rise and fall of the water in the ditch or lateral raises and lowers a float and counterweight. The latter are connected by a cord which passes over the end of a cylinder which is revolved by the cord's movement as the float rises and falls with the changes of depth in the stream. Around this cylinder is fastened a paper divided into rectangular spaces, the time divisions being parallel to its axis and the depth

divisions at right angles thereto. The pen or pencil making the record is moved along this cylinder by clockwork, passing from one end to the other in a week, when the paper is changed and the pen returned to the starting point. The character of the record is shown by the reproduction of a number of these sheets. The fluctuation in discharge creates a zigzag line, a wide variation in depth sometimes

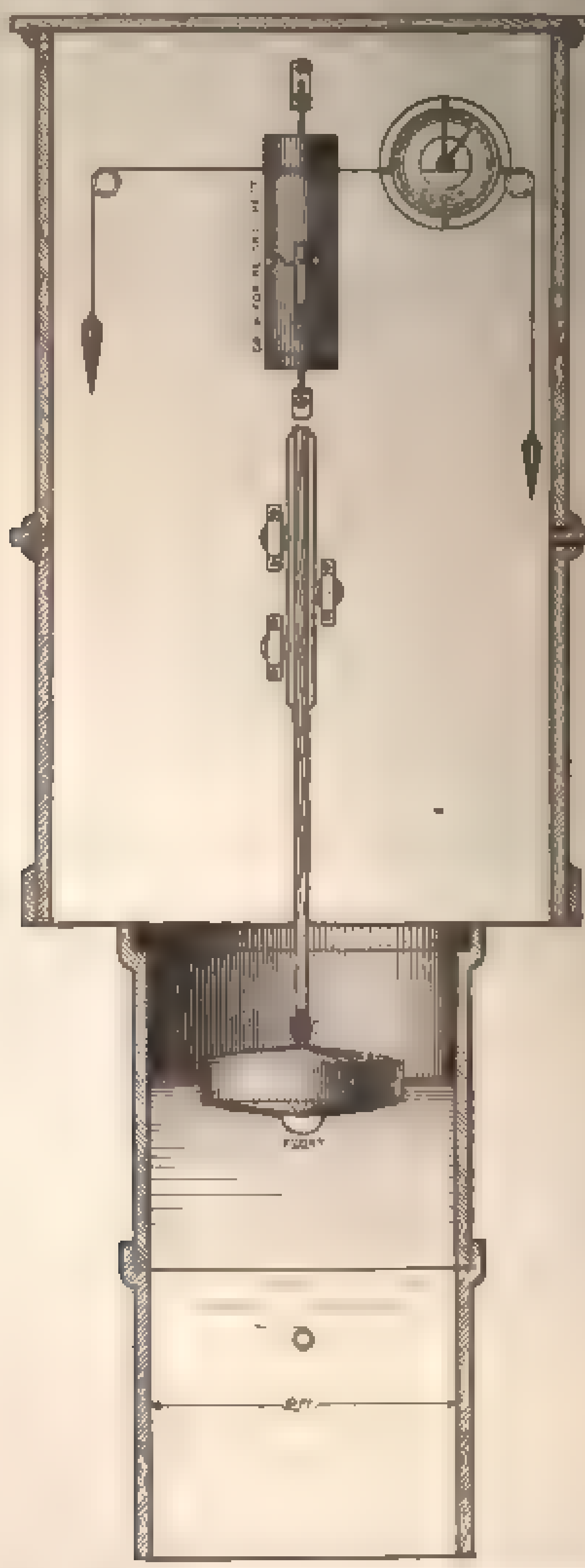


FIG. 4.—Water register used on the Gage Canal

causing the cylinder to make a complete revolution; but as the pen or pencil follows this and records it, any number of revolutions could be made without a loss of the record.

Owing to delay in the construction of these instruments, all observers could not be supplied with them, and a number of registers of

other patterns were used. The Richard Brothers' register (fig. 2) was utilized in the measurements in Arizona, the instruments being loaned by the University of Arizona. The Wyoming nilometer (fig. 3) was used at the Wyoming and Nebraska stations. The Irving register (fig. 4) was used on the Gage Canal in California. The Friez register (fig. 5) is a new form, which will be used in the investigations next year. Fig-

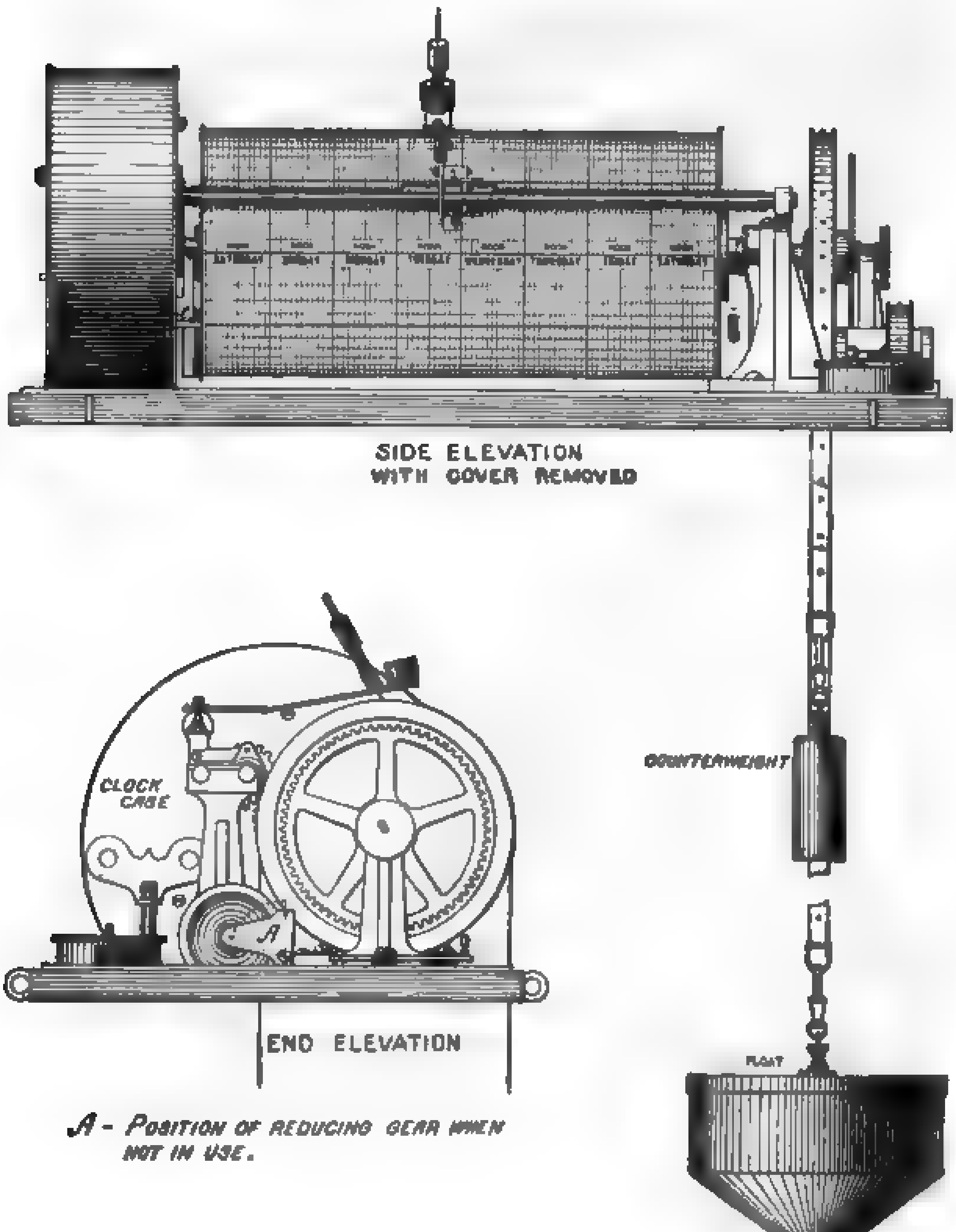


FIG. 5.—Friez water register No. 2.

ures 6, 7, and 8 are copies of sheets taken from the registers in use last year, figure 6 being taken from register No. 1, figure 7 from register No. 2, and figure 8 from register No. 4. The first and last of these give the variations in depth ˏ ˌ ˌle; the second reduces the variations to one-tenth of

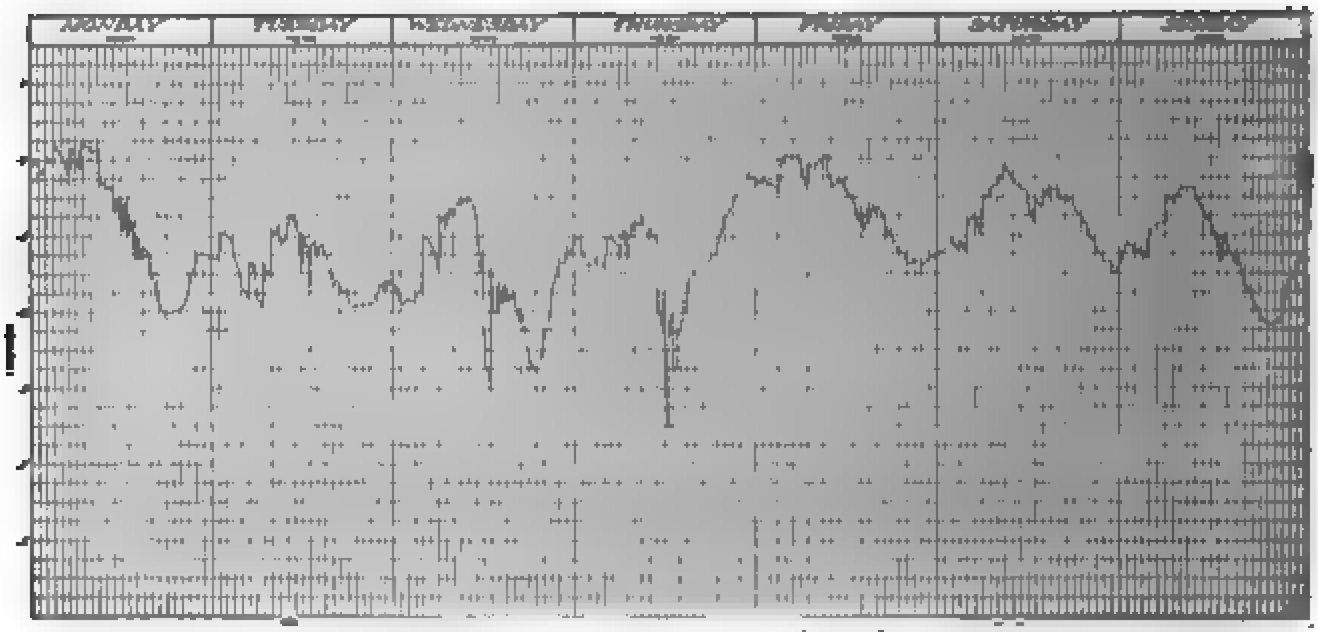


FIG. 6.—Copy of sample water register sheet.

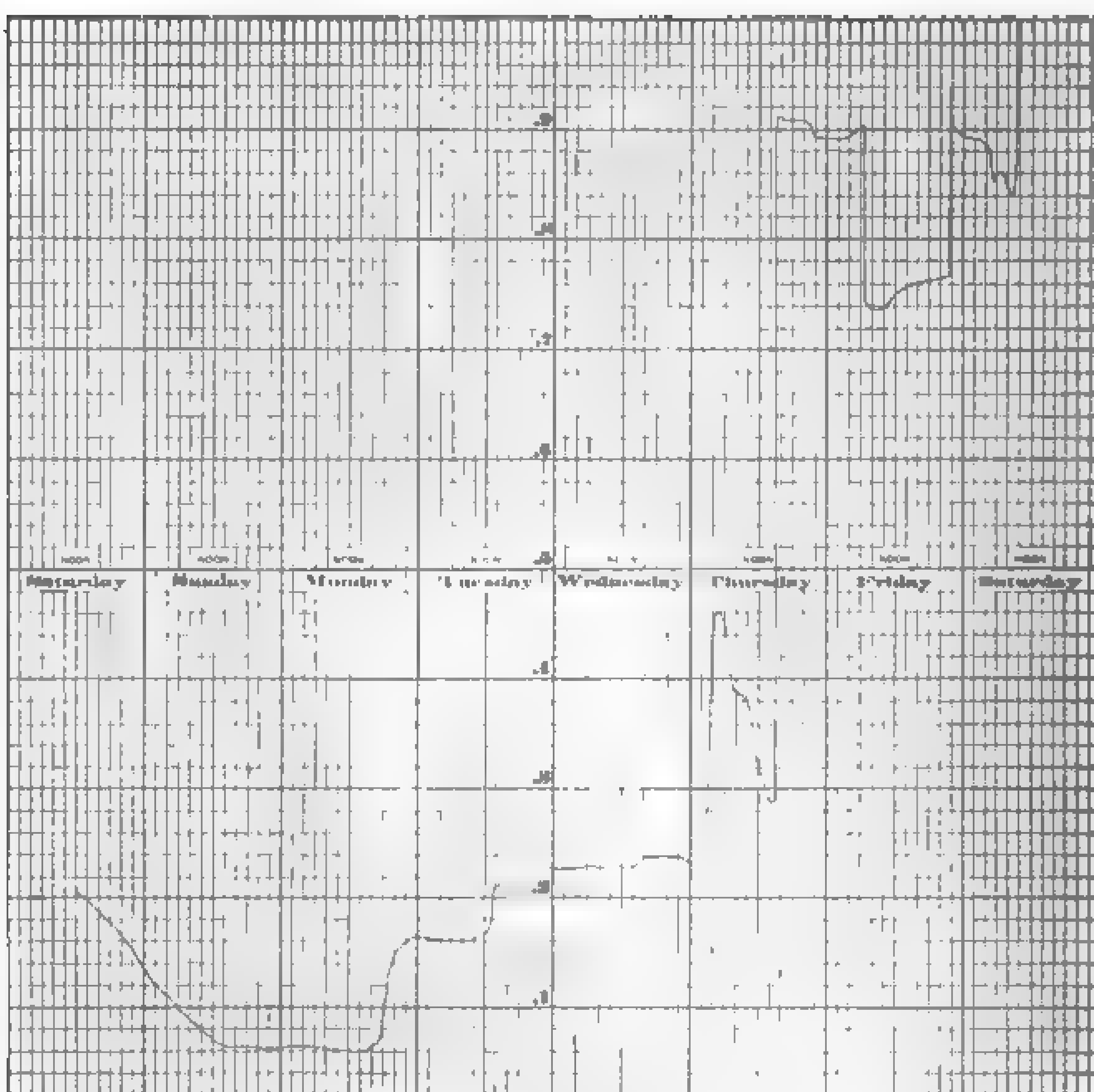


FIG. 7.—Copy of sample water register sheet.

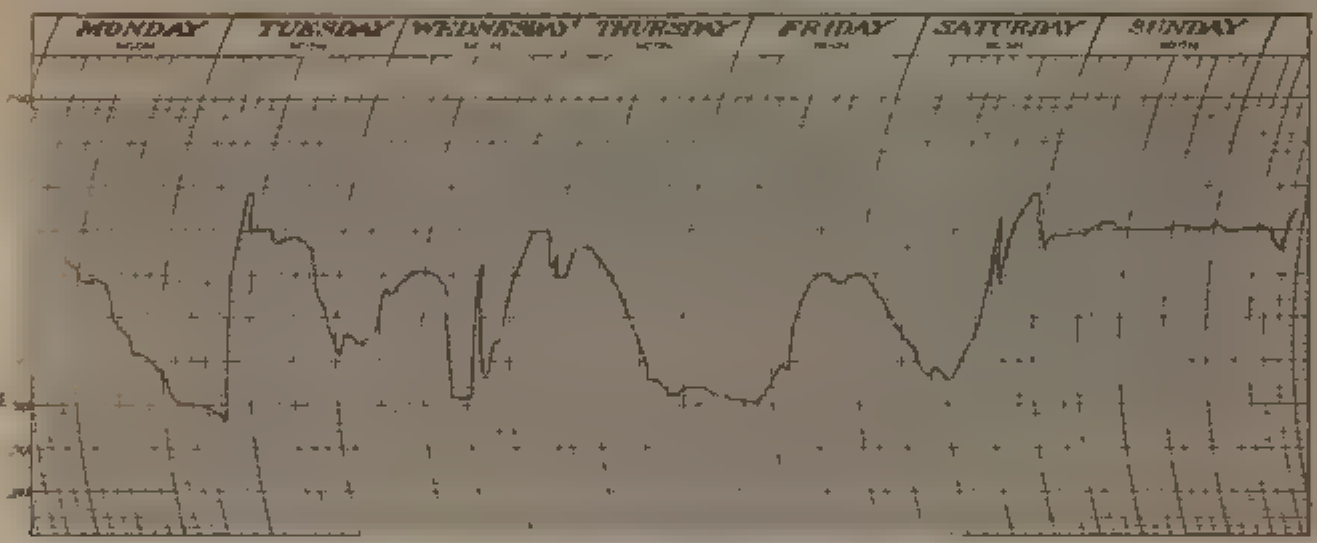


FIG. 8.—Copy of sample water register sheet.

INSTRUCTIONS TO OBSERVERS FOR THE PLACING OF WEIRS AND FLUMES

The following abstract from the instructions to observers gives the regulations governing the placing of measuring weirs and flumes.

WEIRS

Weirs are to be employed wherever the conditions will permit, and where not, a measuring flume is to be substituted. A Cippoletti weir is the form to be used. Figure 9 shows its detail and the method of placing the recording instrument with

FIG. 9.—Cip [illegible] weir in place.

sufficient clearness to permit of its proper construction. The following directions should be observed:

(1) The dimensions of the flume in which the weir is placed will be governed by the volume of water to be measured, but in no case should the length be less than 16 feet nor the width be less than the surface water line of the ditch. The bottom of the flume should be level in both directions. Its upstream end should be placed on grade with the bottom of the ditch, so that water will enter without eddies or disturbance. The channel of the ditch should have a uniform grade and cross section for 100 feet upstream from the flume, and its axis should pass through and be parallel to the middle of the structure.

(2) The length of the weir should be sufficient to permit all water needed to pass over it without the depth in any case exceeding 2 feet.

(3) The end and bottom contractions of the weir must be complete. To secure this, (a) the crest of the weir must be horizontal, and the sides must be inclined to a vertical line at an angle whose tangent is 0.25; (b) the crest of the weir must be perpendicular to the axis of the ditch; (c) the upstream edge of both crest and sides of the weir must be sharp, and the walls cut away therefrom to prevent the creation of a vacuum; (d) the distance of the crest of the weir from the bottom of the flume must be three times the maximum depth of water intended to pass over the weir, and the distance from the end of the crest of the weir to the sides of the flume must not be less than twice the maximum depth of water to flow over the weir.

(4) The float which actuates the recording instrument should be placed far enough away from the weir to secure an accurate measurement of depth. This is 6 feet in the sketch. Connection with the well should be by one-half-inch orifice through the sides of the flume and well.

(5) A post for checking the record of the register should be fastened to the bottom or side of the flume, with a nail in its top exactly level with the crest of the weir. The accuracy of recorded depths should be tested each time the sheet on the register is changed.

(6) The depth of water on the weir can be determined by the following method: Having the perpendicular distance from the top of a crossbeam to the top of the post referred to (5), measure the distance from the top of the crossbeam to the water surface either with finely graduated scale or hook gauge. The difference between these two distances will give depth of water required.

MEASURING FLUMES.

Figure 10 is an isometric projection of the measuring flume proposed to be used where conditions do not permit of a weir. In constructing these flumes the following requirements should be observed:

(1) Bottom of flume (fig. 10) should be horizontal in both directions; the sides vertical. The length must in no case be less than 12 feet nor less than twice the width of the ditch or canal, and width must be equal to width of ditch on the bottom.

(2) The upstream end should have a submerged apron, extending 2 feet below the bottom, to prevent leakage. The wings at the side should extend into the bank beyond the surface water line of the ditch, and the angle of inclination to the axis of the ditch should not exceed 30 degrees.

(3) The channel of the ditch should have a uniform grade and cross section for 100 feet upstream from the flume, and should be straight for that distance, with its axis passing through the middle of the flume and parallel to it.

(4) The well for the register float should be placed three-fourths of the distance from the upstream end of the flume and be connected with the water therein by an orifice one-half inch in diameter.

(5) The well for the register float for both weirs and flumes should be made large enough to contain both float and counterweight, in order to protect them from the

action of the wind. To do this it should be 10 by 16 inches inside measurement in cross section, and its height above the bottom of the flume should be more than double the maximum depth of water the flume will carry.

(6) Where the water carries solid matter in suspension the bottom of the flume should be about one-tenth of a foot above the grade of the ditch, so that all silt may be carried through and not permitted to settle and destroy the form of cross section.

(7) The foundation timbers of all structures should be solidly embedded, and the earth around them and around the sides of the structure carefully and solidly rammed, in order to prevent any subsequent settlement or passage of water around either the bottom or sides.

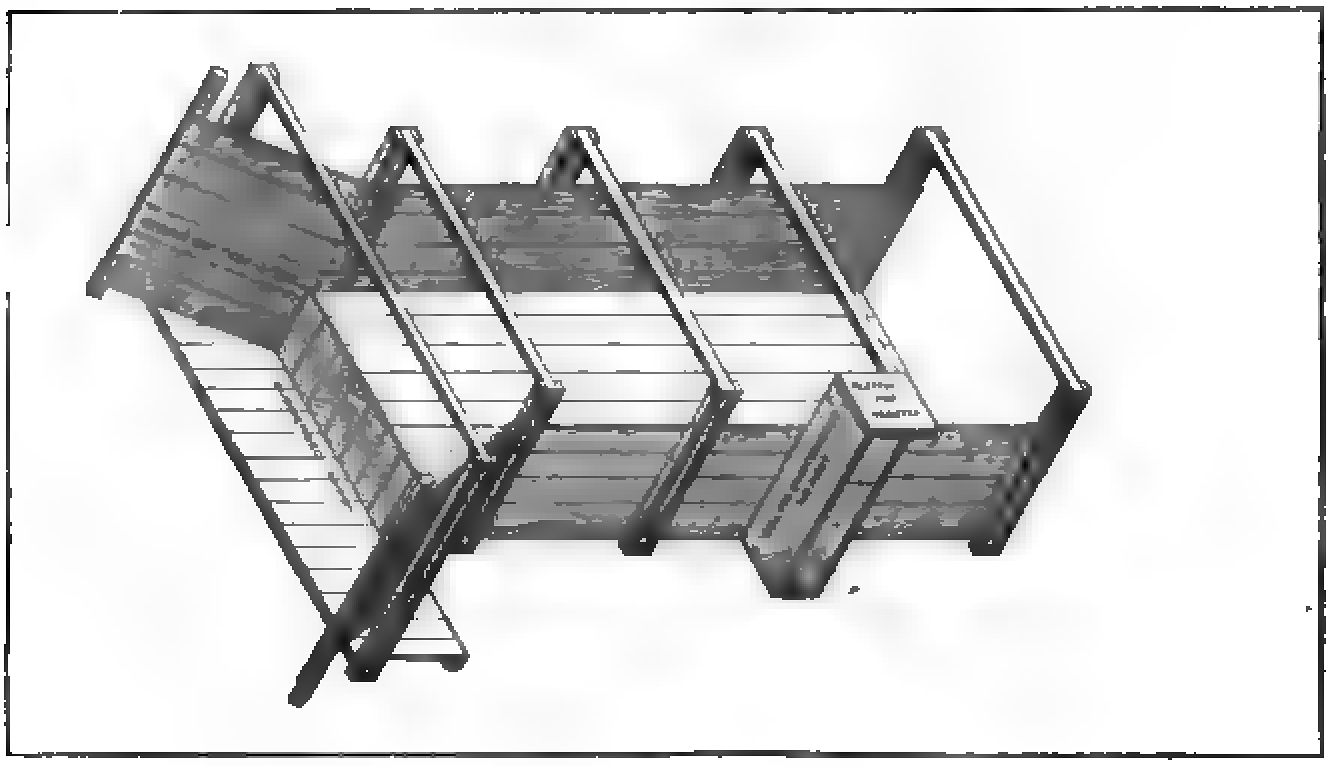


FIG 10.—Measuring flume, showing place for water register.

The following instructions should be observed in placing the register:

The distance from the bottom of the register to high-water mark must be 6 inches more than the total rise and fall of the water.

Record sheets provide for eight days, but clocks should be wound and paper changed once each week. The sheets are designed for this to be done on Saturday.

The accuracy of the registered depth of water flowing over a weir or in a flume should be tested before and after the change of each sheet. Any inaccuracies in either depth or time should be noted on the sheet when observed and the same corrected. Care should be observed in returning pen to starting point that the gear and pinion do not become marred. The ball bearings should be oiled once each month. The ink in the pen, if a pen is used, should be renewed each week.

The report of land irrigated and the register sheets showing the depth of water should be mailed each week to the Cheyenne office.

LIST OF OFFICIAL STATIONS AND OBSERVERS.

The studies have been made by the following observers, at the places named:

Official stations for irrigation investigations, and names of observers.

State.	Location.	Observer.
New Jersey	New Brunswick	Prof. E. B. Voorhees, of the New Jersey Experiment Station.
Nebraska[1]	Gothenburg	A. M. Allen.
	Lincoln	Prof. O. V. P. Stout, of University of Nebraska.
Montana	Bozeman	Prof. S. Fortier, of the Montana Experiment Station.
Wyoming	Wheatland	M. R. Johnston.
	Laramie	Prof. B. C. Buffum, of the Wyoming Experiment Station.
Colorado	Holly	Thomas Berry, chief engineer Great Plains Water Co.
Texas	Beeville	S. A. McHenry, of the Texas Experiment Station.
New Mexico[2]	Carlsbad	W. M. Reed, chief engineer Pecos Valley Irrigation Co.
	Mesilla Park	Prof. C. T. Jordan, of the New Mexico Experiment Station.
Arizona	Phœnix	W. H. Code, chief engineer Consolidated Canal Co.
California	Riverside	W. Irving, chief engineer Gage Canal Co.
Utah	Logan	Prof. Geo. L. Swendsen, of the Utah Experiment Station.
	Salt Lake City	R. C. Gemmell, State engineer.
Idaho	Boise	D. W. Ross, State engineer.

[1] The State engineer of Nebraska, J. M. Wilson, also cooperated with this investigation in the collection of data.

[2] Records of the duty of water at Aztec and East Las Vegas are also being furnished us by the New Mexico Agricultural Experiment Station.

RELATIVE MERITS OF WEIRS AND FLUMES IN THE MEASUREMENT OF WATER.

Reference has already been made to the fact that some of the weirs put in did not prove satisfactory. This was due to the deposit of silt above them. Sediment investigations made during the season showed that certain Southern streams carry, during floods, as high as 5 per cent of solid matter in suspension, and that canals and laterals taking water from these streams have to be cleaned from two to three times each year. Even where the percentage was much less than this, the deposit of sediment was so rapid in some cases as to fill the lateral or ditch above the weir to a level with its crest in twenty-four hours. Where this happened the velocity of approach became a disturbing factor, the influence of which could not be determined owing to the constant change of conditions. Some canal companies which employ weirs operate in connection therewith a sluicing device which removes the accumulated sediment once each day, but the objection to this is that the conditions are never stable and it is impossible to tell for what length of time weir tables used agreed with the actual discharge. The recent investigations in the flow of water over dams and over weirs, other than those with sharp edges, may aid in securing the adoption of a form of weir better suited to the sediment-laden waters of the Southwest than that employed, but so far as knife-edged weirs are concerned there are few ditches in that section where it is not possible to secure rating tables for flumes which will give much more reliable and accurate results. It was also found that in a number of canals the grades were too small and the banks too low to

FIG. 1.—WEIR AT HEAD OF BIG DITCH, BIG COTTONWOOD CREEK, UTAH.

FIG. 2.—MEASURING WEIR AND REGISTER, MONTANA AGRICULTURAL EXPERIMENT STATION.

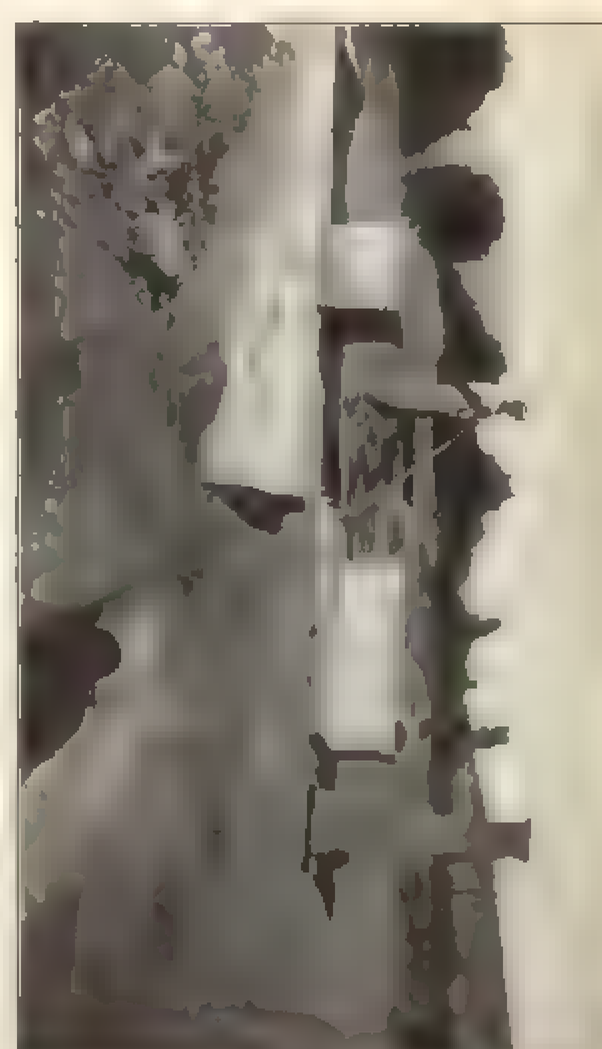


FIG. 3.—MEASURING FLUME AND REGISTER, GAGE CANAL, NEAR RIVERSIDE, CAL.

FIG. 4.—RATING FLUME NO. 1, KICKING BIRD CANAL, COLORADO.

secure the requisite fall below the weir, and in such cases flumes would not only be preferable, but an inevitable substitute.

The most serious objection to the use of flumes is the labor of preparing accurate rating tables, and the fact that a current meter is required for doing this. The recent improvements in these instruments, by which their convenience and accuracy have both been increased, has made it a simple matter to prepare a discharge table for flumes in which the flow is reasonably uniform. With ordinary care this discharge can be determined within the limits of accuracy permitted by the meter employed, and in the best instruments this error is as low as 1 per cent. This margin of error is below what is permissible in the delivery of water or attainable in this investigation.

THE UNIT OF MEASUREMENT EMPLOYED IN DISCUSSING THE DUTY OF WATER.

In the tables which follow the acre-foot is the unit of volume employed. This is, however, sometimes expressed by giving the equivalent depth to which the water used would have covered the surface irrigated.[1] This unit was chosen because it is definite and because it affords a convenient base for the comparison of quantities used in localities where the period of use was not the same.

It is usual in discussions of the duty of water to take a cubic foot per second as the unit of quantity and the period during which a crop requires water to bring it to maturity as the time during which the flow of that volume continues. Thus, when it is said that the duty of water is 60 or 80 acres to the cubic foot per second, the statement implies that the quantity of water used during the season had been measured and the average volume used during this season amounted to a cubic foot per second for each 60 or 80 acres irrigated. In order to make this expression definite, it is necessary that the duration of the irrigation period be known; but this varies so widely in actual practice and in different localities that it is difficult to compare the results obtained where both the volume used and the time of use are variables which have to be considered. Hence, the duration of the irrigation season or base, as it is often called, is usually assumed. In a number of discussions of this subject the assumed base for the Rocky Mountain regions has been taken as varying from one hundred to one hundred and fifty days. The records kept last year show, however, that water was used from the Gage Canal at Riverside, Cal., throughout the entire year, while the canal at Wheatland, Wyo., was only operated sixty days and water was used in irrigation a shorter time. Since the base or period of use varies so widely any attempt at fixing an average one would be wholly arbitrary. Even under the same

[1] This is really the reciprocal of the duty of an acre-foot, but its use is a convenience and involves no confusion of meaning.

canal the length of the season has to be assumed, because no two irrigators use water for the same length of time. The length of the irrigating period at the several stations is shown graphically in the accompanying diagrams (Pl. III). Nor does the assumption of a continuous flow accord with practice, because on many canals a system of rotation is already in operation in the delivery of water, and even where the contracts provide for a constant delivery it seldom happens that irrigators use water in this way. When, therefore, in practice 20 miner's or statutory inches are used on an acre for a day and none at all for the next twenty days it is misleading to discuss the duty as though a single inch had been used all the time. In nearly all of the Northern States fully three times as much water is used in July as in August. Hence, a discussion which deals with the delivery of water as though the use was uniform during this period is liable to lead to serious mistakes in practice.

By the use of the acre-foot as the unit of quantity, all of the arbitrary assumptions involved in the use of either the "inch" or the cubic foot per second are avoided, and its employment is equally correct and convenient whether the supply comes from streams, wells, or reservoirs, whether the use is continuous or intermittent, and whether it ends in two months or extends throughout the entire twelve. The flow of a cubic foot per second for twenty-four hours amounts to 1.98 acre-feet, so that the conversion of volumes from one unit to the other can be readily made.

SUMMARY OF MEASUREMENTS OF DUTY OF WATER.

The measurements made by observers show that the duties obtained vary from less than 1 acre-foot of water per acre irrigated to the use of over 15 acre-feet on an acre, but these wide and seemingly eccentric variations in the quantities used were the results of manifest causes. Where water was distributed through well-built ditches and used by careful irrigators there was a surprisingly close agreement in results, even in widely separated localities. The following table will serve to illustrate this:

Duty of water where measurements were made on small canals or laterals.

Location:	Acre-feet.
Cronquist farm, Utah	2.60
Long farm, Idaho	2.40
Gage Canal, California	2.24
Canal No. 2, Wyoming	2.53
Vance farm, Arizona	2.82
Biles Lateral, Colorado	[1] 1.82
Middle Creek Ditch, Montana	2.10
Daggett farm, Nebraska	2.47
Mean of all the above	2.37

[1] Low duty due in part to scanty supply of water.

DIAGRAM SHOWING DURATION OF IRRIGATION PERIOD ON MAIN CANALS INCLUDED IN INVESTIGATIONS.

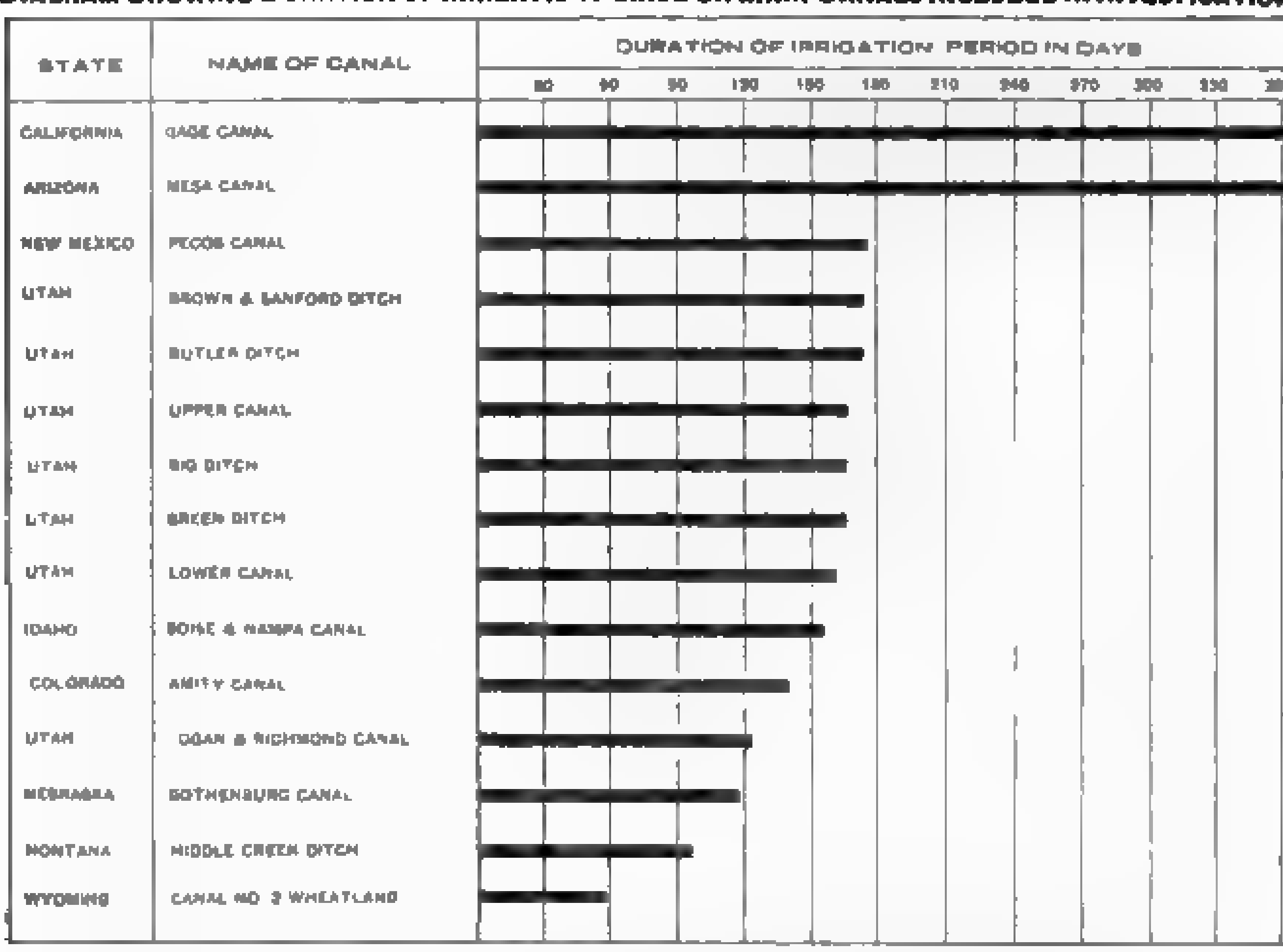
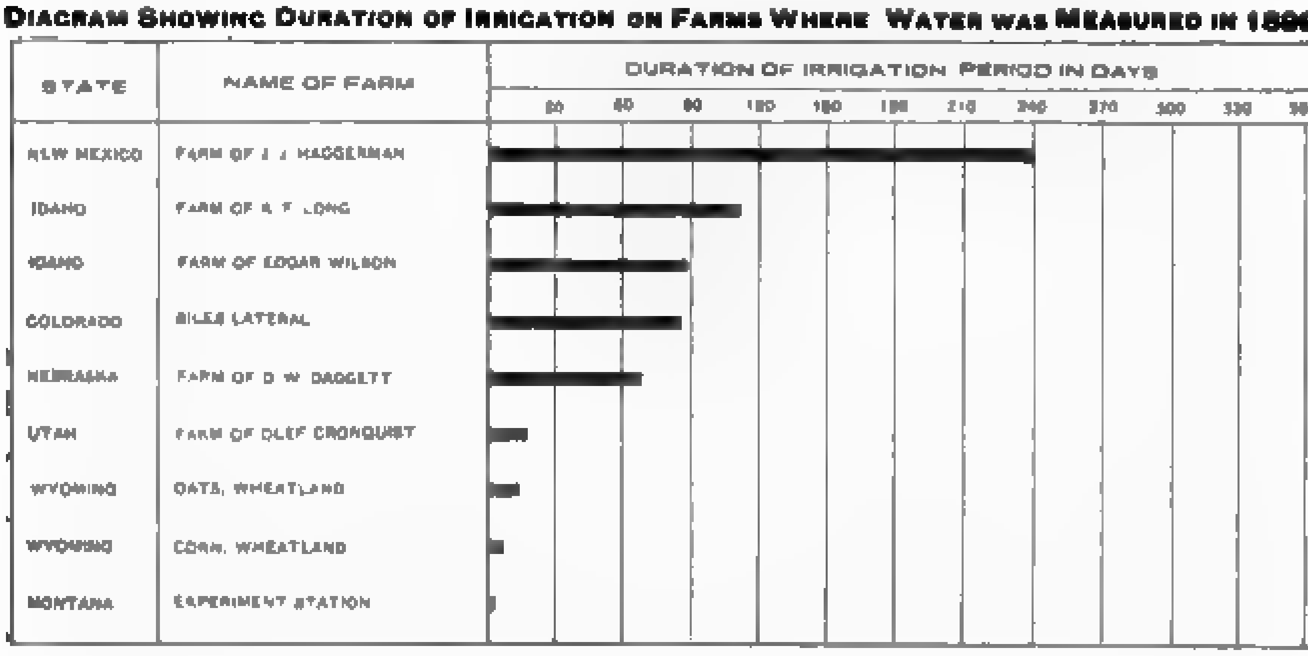


DIAGRAM SHOWING DURATION OF IRRIGATION ON FARMS WHERE WATER WAS MEASURED IN 1899.



DIAGRAMS SHOWING LENGTH OF IRRIGATION SEASON.

An interesting comparison with the above is afforded by the mean of the duties on all of the distributaries of the Ganges Canal for 1889–90, during the khareef season, as reported in Buckley's Irrigation Works in India. Here the mean volume of water used in the irrigation of an acre of land was 121,970 cubic feet, equal to 2.8 acre-feet for each acre irrigated.

Where the water was measured at the margin of the fields there was a still higher duty than where measured at the heads of the laterals. The following table shows the duty obtained where all losses in distribution were eliminated and nothing but the water actually spread over the fields was measured:

Duty of water where measurements were made at margin of fields.

Location:	Acre-feet.
J lateral, Wyoming, oats	1.55
J lateral, Wyoming, corn	.70
Farm, Edgar Wilson, Idaho	1.48
Lowest division, Gage Canal	1.78
Mean of measurements at Bozeman, Mont., Experiment Station	1.20

LOSSES OF WATER FROM CANALS.

The duties given in the foregoing tables were obtained on laterals, or on canals where the losses in transit were not large, and on fields where the water was measured at their margins. They therefore represent, approximately, the volume utilized. In practice, however, the losses in canals from percolation, leakage of flumes, evaporation, etc., are an important factor in fixing the average duty of water from a river or an extensive canal system. To determine this average duty the volume should be measured at the headgate, and the acres it irrigates is the duty which canal managers have to consider in determining the area their works will irrigate. This duty is much lower than that obtained by measurements made on laterals or at the margins of the fields where used, the influence of the losses between the headgate and the heads of laterals being greater than has usually been supposed. Where canals cross gravel beds or gypsum deposits the results closely resemble trying to carry water in a sieve. The following table gives the number of acre-feet used in the irrigation of an acre of land where the measurements were made at the canal headgates, and include the loss from seepage and evaporation:

Duty of water when losses in main canal are included.

Name of canal:	Acre-feet.
Pecos Canal, New Mexico	6.61
Mesa Canal, Arizona	3.81
Butler Ditch, Utah	6.24
Brown and Sanford Ditch, Utah	5.32
Upper Canal [illegible]	6.30
Ami[illegible]	4.92
B[illegible]	5.08
	5.47

A comparison of the duties in the above table with those obtained when the water was measured where used will show that more than twice as many acre-feet were required where the water was measured at the headgate as where measured at the place of use; or, in other words, the losses in the canals from seepage and evaporation amount to more than one-half the entire supply. This is in accord with many of the measurements made on irrigation canals in India. Among those recorded in Buckley's Irrigation Works in India is one which shows that the irrigation of wheat under the Jamda Canal, in Bombay, required 5.6 acre-feet of water for each acre irrigated where the water was measured at the head of the canal, but where the water was measured at the place of use it required, in two experiments, only 2.1 acre-feet and 1.4 acre-feet to irrigate an acre, the loss in the canal being more than 50 per cent. On the Hathmati Canal, in the same country, the loss from seepage and evaporation was 50 per cent. These losses in transit are much heavier than is the rule on the older canals of India, and are doubtless more general than they will be in this country when the banks of canals are older and when they are operated with greater regard for economy.

The report of Mr. Reed (p. 109) shows that 47.7 per cent of the water turned in at the head of the Pecos Canal reached the consumers, while 52.3 per cent was lost through seepage and evaporation. The causes of this loss are explained to be the checking of the velocity in the canal by dams in order to throw water on ground too high to be irrigated without this, certain defects in construction, and the nature of the soil in which the canal is built. The canal has a bank on one side only. This has produced stagnant lakes and pools on the upper side wherever the canal crosses ravines or where the ground on the upper side is so low that the water overflows it when the canal is filled. Mr. Reed's report also shows the variation in rate of seepage due to the character of the soil, three-fourths of the water entering one section of the canal 1 mile long being lost. To his summary of the causes of the great loss of water there may be added the fact that the water used in this canal is taken from reservoirs. Its temperature is already above that of most mountain streams, which facilitates alike its rapid filtration and evaporation. It is perfectly clear, owing to the fact that all of the sediment carried by the river is deposited in the reservoirs. This canal affords an illustration of a lower duty on a particular farm, measuring the water at its margin, than the average under the main canal, measuring the water near the headgates. Mr. Reed points out the causes for this, and shows that it does not illustrate the necessities of irrigation, but the possibilities of waste under encouraging conditions.

The water taken into the Mesa Canal during the four years that measurements have been made has varied from enough to cover the land to a depth of 5.9 feet in 1896 to 3.8 feet in 1899. A measurement

was made in 1899 of the water used on a farm where the land had not before been irrigated and where more than the average amount of water was required. Owing to the fact that rotation was practiced on the lateral leading to this farm, it is impossible to determine the exact quantity lost in passing through it, but the water delivered at its head for this farmer would have covered the land to a depth of only 2.8 feet. The difference between the average depth under the main canal and the depth of water used on this farm was just 1 foot, or a difference in quantity of 1 acre-foot per acre irrigated. Mr. Code estimates that this difference would have been much larger if the loss in transit through the lateral had been determined. As it is, this shows a loss of over 25 per cent.

The construction of the Gage Canal is such as to make losses through seepage practically nothing, owing to the canal being cemented. The loss from evaporation is also small, because the canal is deep and narrow and has throughout its length a uniform cross section, with no pools of still water on the upper side. As compared to losses varying from 25 to 75 per cent shown in other canals, the loss of only 6 per cent in this canal has great significance. The water turned into the head would have served to cover the land irrigated to a depth of 2.24 feet, while the mean depth for the water delivered to irrigators' laterals was 2.11 feet, a loss of only 0.13 of an acre-foot per acre irrigated. Canals can only be cemented on earth, as is done in California, in localities where frosts in winter are not severe. There are other remedial measures which can be employed in other sections which will no doubt be largely adopted when the extent of the loss from this source is more generally realized. Dumping clay into the canal and causing it to be distributed by agitating the water has been tried with good results on some Nebraska ditches.

The report of the careful and interesting investigations of Professor Fortier at the Montana Agricultural Experiment Station shows that in the Middle Creek Canal nearly 22 per cent of the total flow was lost in seepage in the first 4 miles, while the probable loss in the entire canal was 35 per cent. The conclusions of Professor Fortier are in accord with those of other observers as to both the evils resulting from this loss and the methods by which it may be reduced.

The water taken into the Logan and Richmond Canal would cover the entire area it irrigates to a depth of 3.59 feet. The water actually used on the Cronquist farm would have covered it to a depth of only 2.6 feet, the difference between the average duty under the canal and the measured duty on one farm under it being nearly 1 acre-foot of water for each acre irrigated, or a difference of about 28 per cent. It is believed that this can be fairly taken as the loss resulting from seepage and evaporation in carriage.

The water entering the headgate of the Amity Canal in Colorado

would have served to cover all of the land irrigated to a depth of 4.92 feet. The water delivered from the Biles Lateral would have covered the land under that lateral to a depth of only 1.82 feet. The difference between the average duty under the canal and the special duty under one lateral is 63 per cent. This seems to indicate that more than one-half of the water taken from the river disappears before it reaches the place of use. An examination of the map of the Amity Canal (Pl. XLI, p. 160) will show the reason for this excessive loss. The canal is a large, long one and much of the time last season was only partly filled. More than one-half of the time the water flowing through it was spread out in a broad, thin sheet, which reduced its velocity and gave abundant opportunity for the continuous sunshine to raise the temperature. This increase in temperature facilitated both its disappearance in the air and its filtration through the soil. Mr. Berry's report shows that the season of 1899 was unusually windy, making evaporation greater than usual.

Enough water was taken into Canal No. 2 at Wheatland, Wyo., to have covered all of the land irrigated to a depth of 2.53 feet, while only enough water was delivered through the J Lateral of that canal to cover the two fields on which the water used in irrigation was measured to a depth respectively of 0.7 and 1.55 feet, the apparent loss in the canal being one-half the water entering it. In this case this high rate of loss is what might have been expected. The canal is long. It traverses a steep hillside slope for 2 miles, in which distance the loss under the lower bank is excessive. In many places the bottom is gravel, through which water escapes freely.

In order to more carefully study the variations in these losses, arrangements were made early last season by Frank C. Kelsey, city engineer of Salt Lake City, Utah, to measure the seepage loss from the Jordan and Salt Lake Canal, from the Jordan River. This canal is 29 miles long, with a bottom width of 20 feet. It originally had a grade of 2 feet per mile, but when measured was in bad condition, with a flow of 30 cubic feet per second at the head. The loss in 29 miles was 45 per cent.[1]

The losses from seepage in new canals are excessive. For the past six months 500 inches of water have been flowing in at the head of a 10-mile lateral built at Billings, Mont., in 1899, but as yet not a drop has reached the lower end.[2] On a canal built in Salt River Valley, Wyoming, there was a loss in 1896 of 10 cubic feet per second in a distance of 100 feet, which continued for several weeks, with no apparent prospect of the loss diminishing. This was about one-third of the canal's flow. The canal was then abandoned. The canals which

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[1] Letter, F. C. Kelsey, city engineer.

[2] Statement of I. D. O'Donnell, Billings, Mont.

take water from the North Platte River are all subject to excessive losses when first built, because of the sandy soil through which they must pass. In high water, however, this river is heavily charged with a white clay, due to the erosion of its banks. When this is deposited on the sides and bottom of ditches, it forms a coating only less impervious than cement, and after a few weeks' operation during high water seepage losses always show great diminution.

Mr. Code reports that the water of Salt River, Arizona, contains a cementing material which in time renders its banks almost water-tight, so long as they remain undisturbed. This has not heretofore been possible on the Mesa Canal because it has been undergoing constant repairs and improvements.

RELATION OF LOSSES IN TRANSIT TO THE AMOUNTS OF APPROPRIATIONS.

This loss from canals has given rise to a number of perplexing questions regarding appropriations. The States of Nebraska, Wyoming, and Idaho have fixed a maximum limit on the amount of water per acre which an appropriator can acquire. In two of these States no one is permitted to appropriate more than 1 cubic foot per second for each 70 acres irrigated. This limitation has given rise to the question as to whether the water so appropriated is to be measured at the margin of the irrigated field or at the head of the canal. Appropriators have claimed that if measured at the headgate the losses in the canal will be so great that the amount delivered will be inadequate for their needs; while water commissioners have insisted that it will be practically impossible to measure each appropriation at the head of the user's lateral. Several contests over this matter have already arisen and sooner or later an authoritative decision will have to be reached. In one instance no water is drawn from a canal for a distance of 11 miles below its head. Measurements were made to determine the loss in this distance and it was found to vary from 18 to 36 per cent. It was urged that this loss was so great that the amount turned into the canal should be increased enough to compensate therefor, but the State authorities refused to recognize this claim on the ground that such a concession would put an end to the improvement of ditches, since the greater the loss the larger the appropriation which would be secured and that its practical effect would be to place a premium on poor construction and wasteful operating of canals.

Much of the water which escapes from canals finds its way to the surface below in the form of springs in what were originally dry ravines. Irrigators have filed on these springs and secured thereby an ample water supply without having to pay the canal company which furnishes it anything for operating expenses or for the purchase of a water right. On the South Platte River alone there are over 400 of

these filings on seepage waters. The report of the State engineer of Colorado for 1898 shows that 5,000 acres in the Poudre Valley were irrigated with seepage water in that year. In a number of instances canal companies have sought to establish a title to the water of these springs and to collect for its transportation from their users; but the decisions of the courts in these cases have been conflicting and no settled policy has as yet been established.

In some cases, where slopes are crossed by several canals, the lowest one frequently is benefited rather than injured by filtration, as it intercepts the water lost above. In one instance, where it is known that a large volume of seepage water is escaping from high line canals, a ditch has been cut parallel with the river bank, but some distance away from it, to intercept this percolating supply. This has led to litigation to determine whether or not this is an interference with the rights of prior appropriators below on the main stream.

The percolating water from canals and irrigated fields materially increases the water supply of Western rivers. Measurements of this return or seepage water have shown that this reaches in many instances 30 per cent of the original volume.

The serious losses from evaporation do not occur in the main canals, but from the fields where water is distributed. During midsummer the continuous sunshine heats the surface of the ground to a very high temperature. A test made last summer showed the surface soil in southern California to have a temperature of 120° F. When a thin layer of water is spread over land thus heated, as is frequently done where flooding is practiced, the loss from evaporation must be excessive. Mr. Reed discusses this in his report (p. 98), showing instances where it has become so great as to entirely absorb the volume supplied. Irrigators know by practice how much faster an irrigation head of water travels over fields at night and in the early morning than during the afternoon. This is due to the difference in the rate of evaporation. In order to lessen this loss it is important that fields be irrigated as quickly as possible. To this end each irrigator should be supplied with all the water he can distribute. Where only a small stream is used progress is slow; the soil next the laterals is supersaturated; it is hard work to reach the high spots while the low ones are overirrigated by the delay this causes. The contracts of the Gothenburg Canal in Nebraska agree to furnish 1 cubic foot per second for 80 acres, but in supplying the owners of small tracts their practice is to give to each patron a flow of and not less than 2 cubic feet per second and then shorten the time of delivery. Professor Stout, special agent in Nebraska, says this plan is much more satisfactory to farmers and to the canal company than to deliver a constant flow of a smaller volume.

INFLUENCE OF FLUCTUATIONS IN SUPPLY ON THE DUTY OBTAINED.

A low duty does not of necessity indicate a wasteful or unskillful use of water. An illustration of this is found on streams which furnish more water than can be used during the flood season, but where the period of plenty is followed by an equally assured period of drought. Irrigators have learned to provide against the latter by pouring on their land all the water it will hold while it can be had. By thus saturating the subsoil they store up a reserve supply which plants draw upon when the ditches fail. The report of Mr. Code deals with this practice, and the diagram of the flow of water in the Mesa Canal (Pl. VI, p. 72) shows graphically how marked is the scarcity during the hottest part of the year. It will be seen by examining this diagram that at the time when the most water would be used, if it could be had, less was actually used than at any other time in the season. That it is better to waste water on the land when there is a surplus than to let it escape down the river and have crops burn later in the season is beyond question, but the results of such irrigation are not nearly so satisfactory as they would be if this flood supply could be stored in reservoirs and be available for use when needed. Mr. Code's report shows clearly the necessity of reservoirs in localities like the Salt River Valley. They are needed to store the floods which now run to waste; they are needed to enable farmers to use water when crops demand moisture and to relieve them from the alternating floods and droughts, which dependence on the stream alone renders inevitable. No one can study Plate VI without realizing the injury to land and to crops which results from the fluctuating use which it discloses.

REQUIREMENTS OF DIFFERENT CROPS.

The instructions to farmers to use water as they had hitherto been in the habit of doing made the results show more clearly than they otherwise would the influence of waste in lowering the duty, and of care and skill in increasing it, but they also made it next to impossible to derive any certain conclusions as to the relative needs of different crops. It is known for example that less water is needed for corn than for alfalfa, but it is possible for a careless irrigator to waste more water on his cornfield than another uses on his alfalfa meadow, and this is what sometimes happens. It is also known that where economy prevails it requires less water for orchards than for alfalfa, and this is the general rule in these measurements; but in the case of Mr. Cronquist, in Utah (see p. 217), the orchard absorbed more water than either the meadow or grain field. This was due to waste in the lateral. It was a parallel case to one cited (p. 98) by Mr. Reed, who, in discussing the benefits of rapid distribution, showed how all the

water entering a small lateral may be dissipated by seepage and evaporation. The study of the relative requirements of different crops demands special preparation and special methods. It is a line of work specially suited to the agricultural experiment stations of the arid States, where it is hoped it will receive increased attention.

THE RETURN RECEIVED FROM THE USE OF AN ACRE-FOOT OF WATER.

The following table, giving the return from the use of an acre-foot of water, was prepared by taking the prices received for the crops grown on an acre of land and dividing it by the water used in the irrigation of that land, the places chosen being taken from among those where water was measured:

Value of the crops matured for each acre-foot of water used.

Average of six crops in Montana	$18.42
Average for crops irrigated from Big Cottonwood Creek, Utah	6.34
Average for crops irrigated from Canal No. 2, Wheatland, Wyo	7.69
Average for crops irrigated from Mesa Canal, Arizona	3.37
Value of crop from almond orchard under Mesa Canal	30.00
Average for crops irrigated from Gage Canal, California:	
Farm No. 1	207.00
Farm No. 2	237.00
Farm No. 3	180.00

THE DIFFERENCE BETWEEN THE DUTY ASSUMED IN CANAL CONTRACTS AND THE DUTY FOUND BY THE YEAR'S MEASUREMENTS.

A comparison of the results of the year's measurements with the duty of water assumed in many important water-right contracts is interesting as showing their agreement with, or departure from, actual practice. Below is given the quantity of water agreed to be furnished by a number of canal companies:

ARIZONA.

Arizona Water Company.—Sells perpetual water rights for 0.83½ cubic feet per second, to be used on not to exceed 80 acres. This gives a duty of a little less than 100 acres per cubic foot per second, or a depth of 7.5 feet on the land irrigated.

Consolidated Canal Company.—Sells perpetual water rights for not to exceed one-third of a miner's inch per acre. This gives a duty of 120 acres per cubic foot per second, or a depth of 6 feet.

Rio Verde Canal Company.—This company sells water by quantity, agreeing to furnish sufficient water to cover land to a depth of 2 feet if it is called for, and more at the option of the company.

CALIFORNIA.

Gage Canal.—Allows 1 inch to 5 acres, or 1 cubic foot per second to 250 acres. This water is not delivered in a continuous flow, but in large streams for short periods, at the convenience of the consumer. This flow gives a depth of 2.89 feet.

COLORADO.

Larimer County Ditch.—Sells water rights for one six-hundredth of the capacity of the ditch, without specifying how much land is to be irrigated.

New Loveland and Greeley Irrigation and Land Company.—Sells one water-right for each 80 acres, allowing a flow of 1.44 cubic feet per second. The Colorado law compels companies to furnish water from April 1 to November 1. For that length of season 1.44 cubic feet per second would cover 80 acres to a depth of 5.3 feet.

Platte Valley Irrigation Company.—Sells a water right for each 80 acres, allowing a flow of 1.44 cubic feet per second, or a depth of 5.3 feet.

Fort Morgan Land and Canal Company.—Sells a water right for each 80 acres, allowing a flow of not to exceed 1.44 cubic feet per second for the irrigating season, or a depth of 5.3 feet.

Arkansas River Land, Reservoir, and Canal Company.—Sells a water right for each 80 acres, allowing a flow of not to exceed 1.44 cubic feet per second, or a depth of 5.3 feet.

Dolores No. 2 Land and Canal Company.—Sells water by the cubic foot per second, without limiting the consumer as to the area which he may irrigate.

IDAHO.

Phyllis Canal.—Contracts provide that the amount of water delivered shall not at any time exceed an amount equivalent to 1 cubic foot per second for 50 acres, and that the total maximum quantity allowed shall not exceed 2 feet in depth on the land irrigated. Since 1899 will sell water by the cubic foot per second, with no limitations as to the area to be irrigated.

Boise and Nampa Canal.—Until 1899 delivered water at the rate of 1 miner's inch to the acre, but not to exceed 3 feet in depth on the land irrrigated. Since 1899 sells water by the cubic foot per second, with no limitations as to the area to be irrigated.

MONTANA.

Minnesota and Montana Land and Improvement Company.—Sells water by the miner's inch without regard to the area to be irrigated. For the season of 1899 the farmers under this company's canal ordered, on an average, 1 miner's inch for 3.77 acres, showing a duty of about 150 acres per cubic foot per second.

NEBRASKA.

North Platte Irrigation and Land Company.—Sells water rights for 1.44 cubic feet per second and describes land on which it shall be used.

Interstate Canal and Water Supply Company (Wyoming and Nebraska).—Agrees to furnish 1 inch per acre, or 1 cubic foot per second, for 50 acres. The legal season in Nebraska is 200 days, from April 15 to November 1. One cubic foot per second will cover 50 acres to a depth of 7.9 feet in that time.

NEW MEXICO.

Pecos Irrigation and Improvement Company.—Water-right contracts provide for the delivery of 43,560 cubic feet of water per acre, sufficient to cover the land to a depth of 1 foot, delivered at such times and in such quantities as may be necessary for the proper irrigation of crops.

TEXAS.

T. C. Purdy.—Water-right contracts call for the delivery of 43,560 cubic feet per acre, to be delivered in not more than 5 irrigations per annum.

WASHINGTON.

Yakima Investment Company.—Contracts to deliver not to exceed 1 cubic foot per second per 160 acres, from April 1 to October 31. This gives a depth of 2.65 feet.

WYOMING.

Wyoming Development Company.—Sells water rights giving the right to part of the total flow of canal.

Fetterman Canal Company.—Sells a water right for each 8 acres, allowing a flow of one-tenth cubic foot per second. Wyoming canals do not ordinarily run more than 60 days. In that time this flow would give a depth of 1.46 feet.

Cody Canal.—Shares represent water for 40 acres, and the quantity delivered is not to exceed one-half cubic foot per second. This gives a depth of 1.46 feet in 60 days.

In the following table is summarized the results of the actual measurements of the duty of water:

Tabular summary of season's measurements of precipitation, evaporation, and duty of water.

Station.	Period during which water was used.	Rainfall.	Evaporation.	General duty.		Special measurements of duty.			Remarks.
				Depth of irrigation.	Depth of irrigation and rainfall.	Location.	Depth of irrigation.	Depth of irrigation and rainfall.	
		Feet.	*Feet.*	*Feet.*	*Feet.*		*Feet.*	*Feet.*	
Carlsbad, N. Mex.: Pecos Canal.	Entire year	[1] 10.31	4.55	6.26	6.57	Hagerman farm	15.44	15.75	Measurements carried on from April to October.
Mesa, Ariz., Mesa Canal:									
1896	do	.78		5.91	6.69				
1897	do	1.04		5.55	6.59				
1898	do	.57		5.01	5.58				
1899	do	.39		3.81	4.20				
Riverside, Cal.: Gage Canal	do	.47		2.24	2.71	District No. 1	2.32	2.79	
						District No. 2	2.23	2.70	
Salt Lake City, Utah:						District No. 3	1.78	2.25	
Butler Ditch	April–September	.49		6.24	6.73				
Brown & Sanford Ditch	do	.49		5.32	5.81				
Upper Canal	do	.49		6.30	6.79				
Green Ditch	do	.49		4.52	5.01				
Lower Canal	do	.49		2.83	3.32				
Big Ditch	do	.49		3.09	3.58				
Logan, Utah: Logan and Richmond Canal.	June–September	.27	3.27	3.59	3.86	Cronquist farm	2.60	2.87	
Lamar, Colo.: Amity Canal	March–September	.91		4.92	5.83	Biles lateral	1.82	2.50	Water used under Biles lateral April to September. Rainfall, Holly, Colo., 0.68 feet.
Gothenburg, Nebr.: Gothenburg Canal.	June 7–Sept. 30	1.26		2.57	3.83	Daggett farm	4.24	5.50	Rainfall April to September. Water used after harvest.
Wheatland, Wyo.: Canal No. 2.	June–August	.37	[2] 1.26	2.53	2.90	J lateral:			
						Oats	1.55	1.92	
						Corn	.70	1.07	
Boise, Idaho: Boise and Nampa Canal.	May–September	.22				Rust lateral	5.06	5.28	
						A. F. Long farm	2.40	2.62	Rainfall at Boise.
						Wilson orchard	1.48	1.70	Do.
Bozeman, Mont.: Middle Creek Ditch.	June 16–Sept. 16	.42	[3] 1.74	2.10	2.52	Station farm:			
						Clover	1.02	1.46	Rainfall, 0.44 foot.
						Peas	1.10	1.51	Rainfall, 0.41 foot.
						Grain	1.98	2.40	Rainfall, 0.42 foot.
						Barley	.98	1.39	Rainfall, 0.41 foot.
						Oats	1.53	1.91	Rainfall, 0.38 foot.
						Do	1.34	1.70	Rainfall, 0.36 foot.
						Do	2.16	2.52	Rainfall, 0.36 foot.
						Do	1.28	1.72	Rainfall, 0.44 foot.

[1] May 1 to November 11, 1899.

[2] Evaporation at Laramie, Wyo.

[3] Evaporation from July 6 to September 30.

NEED OF CONTINUING THE INVESTIGATION.

This report does not deal with all the factors which influence the duty of water, because time did not permit of their study. All of the arrangements for the work performed had to be made after the irrigation season in the South had begun. This included securing special agents, enlisting the cooperation of farmers, placing apparatus in ditches and canals, and in some cases the devising of special instruments. For these reasons the necessity for storage reservoirs has been left for subsequent study and discussion. The subject is of commanding importance, because it can not be considered apart from the fundamental question of who is to own or control the stored water, and what is to be the character of rights to store water from streams. Sooner than is generally realized the public or private ownership of Western rivers is destined to be one of the great social and industrial questions of this country. Their waters are worth more than the land, public or private, through which they flow, and the manner of their disposal will do more to shape Western civilization and promote or retard Western development than all other causes combined. The study of the duty of water is a study of the farmer's needs, and it is hoped that the presentation of these needs will tend to promote the creation of an irrigation system which will make the supplying of his necessities of first importance and be a matter of just pride to the nation.

COMPUTATION OF DISCHARGE RECORDS AND PREPARATION OF DIAGRAMS.

By C. T. Johnston,
Assistant in Irrigation Investigations.

From twenty to thirty stations were maintained during the irrigation season of 1899. From these weekly reports were forwarded to the writer at Cheyenne, where all computations were made under his supervision. The reports consisted primarily of register sheets giving the depth of water flowing in ditches and canals. Register No. 1, which has been described in another portion of the report, was generally employed in the work. Its sheets are 1 foot square, and are divided into time and feet divisions running at right angles to each other. The smallest time division is two hours, shown on a scale of one-eighth inch. The smallest depth or feet division is 0.02 of a foot, which permits the depths shown on the sheets being read to 0.01 foot with ease. The sheets begin with Saturday and run through the following Saturday, thus allowing half a day at each end of the week for the observer to visit the register, change the register sheet, and wind the clockwork. Weekly report cards, giving the depth of rainfall and such other information as would affect the use of water, were received with the register sheets.

COMPUTATIONS.

On September 15 five hundred register sheets were on file in the office. Each station was given a number, beginning with 1 in Texas and running west through New Mexico, Arizona, and California, east through Utah and Colorado, west including Nebraska, Wyoming, and Idaho, and finally terminating with Montana. As the sheets and cards were received they were dated and filed under their station number.

The register sheets give a continuous record of the depth of water passing through a flume or over a weir. The relation between these depths and the corresponding discharges is more or less complex, depending on the perfection of the measuring device. If a weir is used, the velocity of approach may make the relation more complicated, and in case of a rectangular weir the end contractions add difficulty to the computations. The Cippoletti weir has been generally adopted in the work. The relation between the depth and discharge is expressed by the formula $Q=3.3\frac{7}{8}Lh^{\frac{3}{2}}$, where Q is the discharge in cubic feet per second, L is the length of the crest of the weir in feet, and h is the

depth of water flowing over the crest in feet. The only correction to be made when this weir is installed properly is for the velocity of approach. Whenever this exceeds one-half foot per second the results must be increased slightly. Where flumes are properly constructed they afford a simple means of measuring water, and the relation between the discharge and the corresponding depths is less complex than in case of weirs.

WEIR TABLES.

Tables giving the discharge of weirs of various lengths and depths have been prepared and published many times. None fill the requirements of this investigation, as the range of depths and lengths of the crests are not sufficient. It being impossible to compile from the various sources satisfactory tables, the preparation of new ones was undertaken. The tables were computed from the formula of the Cippoletti weir. They include weirs from 1 to 10 feet in length, and depths ranging from 0.01 foot to one-fifth the length of the weir. As some stations had used weirs 1.5 feet in length, it was included in the table. Table No. 2 was derived from Table No. 1 by dividing each discharge of the latter by 6.05. Table No. 2 is in acre-feet for a period of two hours. The divisor 6.05 is obtained from $\frac{43560}{7200}$, or the number of square feet in an acre divided by the number of seconds in two hours. Table number No. 2 has been used in the reduction of the register sheets, the smallest time division on which is two hours. The depth can be seen at a glance, and the corresponding discharge can be taken from the table. This table should prove of value to those having the measurement of water in charge, as it eliminates the time feature of the cubic foot per second and yet puts the results in a comprehensive unit.

Many rectangular weirs are already in existence and several agents have employed this type. It is often the more convenient form in large canals. Where the velocity of approach is not excessive and the grade of the canal will warrant it a weir can be installed in a flume or other structure. Often this can be done only when the section of the canal can not be reduced in width. By the use of a rectangular weir without end contractions this can be accomplished and approximate results obtained.

To enable the reports from such stations to be computed Tables Nos. 3, 4, 5, 6, and 7 have been prepared. The first two of these tables give the discharge of rectangular weirs without end contractions in cubic feet per second and acre-feet for two-hour periods. Tables 5 and 6 give the discharge of weirs with end contractions in the same units. Table 7 gives the discharge in both units of rectangular weirs without end contractions for each foot in width. The fourth column of *this table* contains the contraction correction in cubic feet per second.

TABLE 1.—*Discharges of Cippoletti weirs of different lengths, computed from the formula* $Q=3.3\tfrac{2}{3}\,Lh^{\frac{3}{2}}$.

Depth of water on crest.	1-foot weir.	1½-foot weir.	2-foot weir.	3-foot weir.	4-foot weir.	5-foot weir.	6-foot weir.	7-foot weir.	8-foot weir.	9-foot weir.	10-foot weir.
Feet.	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*
0.01	0.0034	0.0051	0.0067	0.0101	0.0135	0.0168	0.0202	0.0236	0.0269	0.0303	0.0337
.02	.0095	.0143	.0190	.0286	.0381	.0476	.0571	.0667	.0762	.0857	.0952
.03	.0175	.0262	.0350	.0525	.0700	.0875	.1050	.1225	.1400	.1574	.1749
.04	.0269	.0404	.0539	.0808	.1077	.1347	.1616	.1885	.2155	.2424	.2693
.05	.0376	.0565	.0753	.1129	.1506	.1882	.2258	.2635	.3011	.3388	.3764
.06	.0495	.0742	.0990	.1484	.1979	.2474	.2969	.3464	.3958	.4453	.4948
.07	.0624	.0935	.1247	.1871	.2494	.3118	.3741	.4365	.4988	.5612	.6235
.08	.0762	.1143	.1524	.2285	.3047	.3809	.4571	.5333	.6095	.6856	.7618
.09	.0909	.1364	.1818	.2727	.3636	.4545	.5454	.6363	.7272	.8181	.9090
.10	.1065	.1597	.2129	.3194	.4259	.5323	.6388	.7452	.8517	.9582	1.0646
.11	.1228	.1842	.2457	.3685	.4913	.6141	.7370	.8598	.9826	1.1054	1.2283
.12	.1399	.2099	.2799	.4198	.5598	.6997	.8397	.9796	1.1196	1.2595	1.3995
.13	.1578	.2367	.3156	.4734	.6312	.7890	.9468	1.1046	1.2624	1.4202	1.5780
.14	.1764	.2645	.3527	.5291	.7054	.8818	1.0581	1.2345	1.4108	1.5872	1.7336
.15	.1956	.2934	.3912	.5868	.7823	.9779	1.1735	1.3691	1.5647	1.7603	1.9559
.16	.2155	.3232	.4309	.6464	.8619	1.0773	1.2928	1.5083	1.7237	1.9392	2.1547
.17	.2360	.3540	.4720	.7079	.9439	1.1799	1.4159	1.6519	1.8878	2.1238	2.3598
.18	.2571	.3857	.5142	.7713	1.0284	1.2855	1.5426	1.7997	2.0568	2.3139	2.5710
.19	.2788	.4182	.5576	.8365	1.1153	1.3941	1.6729	1.9518	2.2306	2.5094	2.7882
.20	.3011	.4517	.6022	.9034	1.2045	1.5056	1.8068	2.1079	2.4090	2.7101	3.0112
.21	.3240	.4860	.6480	.9720	1.2960	1.6199	1.9439	2.2679	2.5919	2.9159	3.2399
.22	.3474	.5211	.6948	1.0422	1.3896	1.7370	2.0844	2.4318	2.7792	3.1266	3.4740
.23	.3714	.5570	.7427	1.1141	1.4854	1.8568	2.2281	2.5995	2.9709	3.3422	3.7136
.24	.3958	.5938	.7917	1.1875	1.5834	1.9792	2.3750	2.7709	3.1667	3.5625	3.9584
.25	.4208	.6312	.8417	1.2625	1.6833	2.1042	2.5250	2.9458	3.3666	3.7875	4.2083
.26	.4463	.6695	.8927	1.3390	1.7853	2.2317	2.6780	3.1243	3.5707	4.0170	4.4633
.27	.4723	.7085	.9447	1.4170	1.8893	2.3617	2.8340	3.3063	3.7787	4.2510	4.7233
.28	.4988	.7482	.9976	1.4964	1.9952	2.4941	2.9929	3.4917	3.9905	4.4893	4.9881
.29	.5258	.7887	1.0515	1.5773	2.1031	2.6289	3.1546	3.6804	4.2062	4.7319	5.2577
.30	.5532	.8298	1.1064	1.6596	2.2128	2.7660	3.3192	3.8724	4.4256	4.9788	5.5320
.31	.5811	.8716	1.1622	1.7433	2.3244	2.9054	3.4865	4.0676	4.6487	5.2298	5.8109
.32	.6094	.9141	1.2189	1.8283	2.4377	3.0472	3.6566	4.2660	4.8754	5.4849	6.0943
.33	.6382	.9573	1.2764	1.9147	2.5529	3.1911	3.8293	4.4675	5.1058	5.7140	6.3822
.34	.6674	1.0012	1.3349	2.0023	2.6698	3.3372	4.0047	4.6721	5.3396	6.0070	6.6745
.35	.6971	1.0457	1.3942	2.0913	2.7884	3.4856	4.1827	4.8798	5.5769	6.2740	6.9711
.36	.7272	1.0908	1.4544	2.1816	2.9088	3.6360	4.3632	5.0904	5.8176	6.5448	7.2720
.37	.7577	1.1366	1.5154	2.2731	3.0308	3.7885	4.5463	5.3040	6.0617	6.8194	7.5771
.38	.7886	1.1830	1.5773	2.3659	3.1545	3.9432	4.7318	5.5204	6.3091	7.0977	7.8863
.39	.8200	1.2300	1.6399	2.4599	3.2799	4.0998	4.9198	5.7398	6.5597	7.3797	8.1997
.40	.8517	1.2776	1.7034	2.5551	3.4068	4.2585	5.1102	5.9619	6.8137	7.6654	8.5171
.41	.8838	1.3258	1.7677	2.6515	3.5354	4.4192	5.3031	6.1869	7.0708	7.9546	8.8384
.42	.9164	1.3746	1.8328	2.7491	3.6655	4.5819	5.4983	6.4146	7.3310	8.2474	9.1638
.43	.9493	1.4239	1.8986	2.8479	3.7972	4.7465	5.6958	6.6451	7.5944	8.5437	9.4930
.44	.9826	1.4739	1.9652	2.9478	3.9304	4.9130	5.8956	6.8782	7.8608	8.8434	9.8261
.45	1.0163	1.5244	2.0326	3.0489	4.0652	5.0815	6.0978	7.1141	8.1303	9.1466	10.1629
.46	1.0504	1.5755	2.1007	3.1511	4.2014	5.2518	6.3021	7.3525	8.4029	9.4532	10.5036
.47	1.0848	1.6272	2.1696	3.2544	4.3392	5.4240	6.5088	7.5936	8.6783	9.7631	10.8479
.48	1.1196	1.6794	2.2392	3.3588	4.4784	5.5980	6.7178	7.8372	8.9567	10.0764	11.1960
.49	1.1548	1.7321	2.3095	3.4643	4.6191	5.7738	6.9286	8.0834	9.2381	10.3929	11.5477
.50	1.1903	1.7854	2.3806	3.5709	4.7612	5.9515	7.1418	8.3321	9.5224	10.7127	11.9030
.51	....	1.8393	2.4524	3.6785	4.9047	6.1309	7.3571	8.5833	9.8095	11.0356	12.2618
.52	....	1.8936	2.5248	3.7873	5.0497	6.3121	7.5745	8.8370	10.0994	11.3618	12.6242
.53	....	1.9485	2.5980	3.8970	5.1961	6.4951	7.7941	9.0931	10.3921	11.6911	12.9901
.54	....	2.0039	2.6719	4.0079	5.3438	6.6798	8.0157	9.3517	10.6876	12.0236	13.3595
.55	....	2.0598	2.7465	4.1197	5.4929	6.8662	8.2394	9.6126	10.9859	12.3591	13.7323
.56	....	2.1163	2.8217	4.2326	5.6434	7.0543	8.4651	9.8760	11.2868	12.6977	14.1085
.57	....	2.1732	2.8976	4.3464	5.7953	7.2441	8.6929	10.1417	11.5905	13.0393	14.4881
.58	....	2.2307	2.9742	4.4613	5.9484	7.4355	8.9226	10.4097	11.8969	13.3840	14.8711
.59	....	2.2886	3.0515	4.5772	6.1029	7.6287	9.1544	10.6801	12.2059	13.7316	15.2573
.60	....	2.3470	3.1294	4.6940	6.2587	7.8234	9.3881	10.9527	12.5174	14.0821	15.6468
.61	....	2.4059	3.2079	4.8119	6.4159	8.0198	9.6238	11.2278	12.8317	14.4357	16.0396
.62	....	2.4654	3.2871	4.9307	6.5743	8.2178	9.8614	11.5050	13.1486	14.7921	16.4357
.63	....	2.5252	3.3670	5.0505	6.7340	8.4175	10.1009	11.7844	13.4679	15.1514	16.8349
.64	....	2.5856	3.4475	5.1712	6.8949	8.6187	10.3424	12.0661	13.7899	15.5136	17.2373
.65	....	2.6464	3.5286	5.2929	7.0572	8.8215	10.5857	12.3500	14.1143	15.8786	17.6429
.66	....	2.7077	3.6103	5.4155	7.2206	9.0258	10.8310	12.6361	14.4413	16.2465	18.0516
.67	....	2.7695	3.6927	5.5390	7.3854	9.2317	11.0781	12.9244	14.7707	16.6171	18.4634
.68	....	2.8317	3.7757	5.6635	7.5513	9.4392	11.3270	13.2148	15.1027	16.9905	18.8783
.69	....	2.8944	3.8593	5.7889	7.7185	9.6481	11.5778	13.5074	15.4370	17.3667	19.2963
.70	....	2.9576	3.9435	5.9152	7.8869	9.8586	11.8304	13.8021	15.7738	17.7456	19.7173
.71	....	3.0212	4.0283	6.0424	8.0565	10.0706	12.0848	14.0989	16.1130	18.1272	20.1413
.72	....	3.0852	4.1137	6.1705	8.2273	10.2842	12.3410	14.3978	16.4547	18.5115	20.5683
.73	....	3.1497	4.1997	6.2995	8.3993	10.4992	12.5990	14.6988	16.7987	18.8985	20.9983
.74	....	3.2147	4.2863	6.4294	8.5725	10.7156	12.8588	15.0019	17.1450	19.2881	21.4313
.75	....	3.2801	4.3734	6.5601	8.7469	10.9336	13.1203	15.3070	17.4937	19.6804	21.8671

TABLE 1.—*Discharges of Cippoletti weirs of different lengths, computed from the formula* $Q=3.36\frac{2}{3}LH^{\frac{3}{2}}$—Continued.

Depth of water on crest.	1-foot weir.	1½-foot weir.	2-foot weir.	3-foot weir.	4-foot weir.	5-foot weir.	6-foot weir.	7-foot weir.	8-foot weir.	9-foot weir.	10-foot weir.
Feet.	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*
0.76			4.4612	6.6918	8.9224	11.1530	13.3836	15.6142	17.8447	20.0753	22.3059
.77			4.5495	6.8243	9.0991	11.3738	13.6486	15.9233	18.1981	20.4729	22.7476
.78			4.6384	6.9577	9.2769	11.5961	13.9153	16.2345	18.5538	20.8730	23.1922
.79			4.7279	7.0919	9.4558	11.8198	14.1838	16.5477	18.9117	21.2757	23.6396
.80			4.8180	7.2270	9.6360	12.0450	14.4539	16.8629	19.2719	21.6809	24.0899
.81			4.9086	7.3629	9.8172	12.2715	14.7258	17.1801	19.6344	22.0887	24.5430
.82			4.9998	7.4997	9.9996	12.4995	14.9993	17.4992	19.9991	22.4990	24.9989
.83			5.0915	7.6373	10.1830	12.7288	15.2746	17.8202	20.3661	22.9118	25.4576
.84			5.1838	7.7757	10.3676	12.9595	15.5515	18.1433	20.7352	23.3271	25.9191
.85			5.2767	7.9150	10.5533	13.1916	15.8300	18.4683	21.1066	23.7449	26.3833
.86			5.3700	8.0551	10.7401	13.4251	16.1101	18.7952	21.4802	24.1652	26.8502
.87			5.4640	8.1960	10.9280	13.6599	16.3919	19.1239	21.8559	24.5879	27.3199
.88			5.5585	8.3377	11.1169	13.8961	16.6754	19.4546	22.2338	25.0131	27.7923
.89			5.6535	8.4802	11.3070	14.1337	16.9604	19.7872	22.6139	25.4406	28.2674
.90			5.7490	8.6235	11.4980	14.3726	17.2470	20.1216	22.9961	25.8706	28.7451
.91			5.8451	8.7677	11.6902	14.6128	17.5353	20.4579	23.3804	26.3030	29.2255
.92			5.9417	8.9126	11.8834	14.8543	17.8251	20.7960	23.7669	26.7377	29.7086
.93			6.0389	9.0583	12.0777	15.0971	18.1166	21.1360	24.1554	27.1748	30.1943
.94			6.1365	9.2048	12.2730	15.3413	18.4096	21.4778	24.5461	27.6143	30.6826
.95			6.2347	9.3520	12.4694	15.5867	18.7041	21.8214	24.9388	28.0561	31.1735
.96			6.3334	9.5001	12.6668	15.8335	19.0002	22.1669	25.3336	28.5003	31.6670
.97			6.4326	9.6489	12.8652	16.0815	19.2979	22.5142	25.7305	28.9468	32.1631
.98			6.5323	9.7985	13.0647	16.3309	19.5970	22.8632	26.1294	29.3956	32.6617
.99			6.6326	9.9489	13.2652	16.5815	19.8978	23.2141	26.5303	29.8467	33.1629
1.00			6.7333	10.0000	13.4667	16.8333	20.2000	23.5667	26.9333	30.3000	33.6667
1.01							20.5038	23.9211	27.3384	30.7556	34.1729
1.02							20.8090	24.2772	27.7454	31.2135	34.6817
1.03							21.1158	24.6351	28.1544	31.6737	35.1930
1.04							21.4240	24.9947	28.5654	32.1361	35.7067
1.05							21.7338	25.3561	28.9784	32.6007	36.2230
1.06							22.0450	25.7192	29.3933	33.0675	36.7417
1.07							22.3577	26.0840	29.8103	33.5365	37.2628
1.08							22.6719	26.4505	30.2291	34.0078	37.7864
1.09							22.9875	26.8187	30.6499	34.4812	38.3124
1.10							23.3045	27.1886	31.0727	34.9568	38.8409
1.11							23.6230	27.5602	31.4974	35.4346	39.3717
1.12							23.9430	27.9335	31.9240	35.9145	39.9050
1.13							24.2644	28.3084	32.3525	36.3965	40.4406
1.14							24.5872	28.6850	32.7829	36.8808	40.9786
1.15							24.9114	29.0633	33.2152	37.3671	41.5190
1.16							25.2370	29.4432	33.6494	37.8556	42.0617
1.17							25.5641	29.8248	34.0854	38.3461	42.6068
1.18							25.8925	30.2079	34.5234	38.8388	43.1542
1.19							26.2224	30.5928	34.9631	39.3335	43.7039
1.20							26.5536	30.9792	35.4048	39.8304	44.2560
1.21								31.3672	35.8483	40.3293	44.8103
1.22								31.7569	36.2936	40.8303	45.3670
1.23								32.1481	36.7407	41.3333	45.9259
1.24								32.5410	37.1897	41.8384	46.4871
1.25								32.9354	37.6405	42.3455	47.0506
1.26								33.3314	38.0931	42.8547	47.6163
1.27								33.7290	38.5474	43.3659	48.1843
1.28								34.1282	39.0036	43.8791	48.7545
1.29								34.5289	39.4616	44.3943	49.3270
1.30								34.9312	39.9213	44.9115	49.9017
1.31								35.3350	40.3829	45.4307	50.4786
1.32								35.7404	40.8461	45.9519	51.0577
1.33								36.1473	41.3112	46.4751	51.6390
1.34								36.5557	41.7780	47.0002	52.2225
1.35								36.9657	42.2465	47.5273	52.8081
1.36								37.3772	42.7168	48.0564	53.3960
1.37								37.7902	43.1888	48.5874	53.9860
1.38								38.2047	43.6625	49.1203	54.5781
1.39								38.6207	44.1380	49.6552	55.1725
1.40								39.0382	44.6151	50.1920	55.7689
1.41									45.0940	50.7307	56.3675
1.42									45.5746	51.2714	56.9682
1.43									46.0568	51.8139	57.5710
1.44									46.5408	52.3584	58.1760
1.45									47.0264	52.9047	58.7831
1.46									47.5138	53.4530	59.3922
1.47									48.0027	54.0031	60.0034
1.48									48.4934	54.5551	60.6168
1.49									48.9857	55.1086	61.2[illegible]
1.50									49.4797	55.6647	61.[illegible]

TABLE 1.—*Discharges of Cippoletti weirs of different lengths, computed from the formula* $Q=3.3\frac{2}{3}\ Lh^{\frac{3}{2}}$—Continued.

Depth of water on crest.	1-foot weir.	1½-foot weir.	2-foot weir.	3-foot weir.	4-foot weir.	5-foot weir.	6-foot weir.	7-foot weir.	8-foot weir.	9-foot weir.	10-foot weir.
Feet.	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*
1.51									49.9753	56.2222	62.4691
1.52									50.4726	56.7817	63.0907
1.53									50.9715	57.3429	63.7143
1.54									51.4720	57.9060	64.3400
1.55									51.9742	58.4710	64.9677
1.56									52.4780	59.0377	65.5975
1.57									52.9834	59.6063	66.2292
1.58									53.4904	60.1767	66.8630
1.59									53.9990	60.7489	67.4988
1.60									54.5092	61.3229	68.1365
1.61										61.8987	68.7763
1.62										62.4763	69.4181
1.63										63.0557	70.0618
1.64										63.6368	70.7075
1.65										64.2197	71.3553
1.66										64.8044	72.0049
1.67										65.3909	72.6566
1.68										65.9791	73.3101
1.69										66.5691	73.9657
1.70										67.1608	74.6231
1.71										67.7543	75.2825
1.72										68.3495	75.9439
1.73										68.9464	76.6071
1.74										69.5451	77.2723
1.75										70.1455	77.9394
1.76										70.7476	78.6084
1.77										71.3514	79.2793
1.78										71.9569	79.9521
1.79										72.5641	80.6268
1.80										73.1731	81.3034
1.81											81.9819
1.82											82.6622
1.83											83.3445
1.84											84.0285
1.85											84.7145
1.86											85.4023
1.87											86.0919
1.88											86.7834
1.89											87.4768
1.90											88.1720
1.91											88.8690
1.92											89.5678
1.93											90.2685
1.94											90.9709
1.95											91.6752
1.96											92.3813
1.97											93.0892
1.98											93.7989
1.99											94.5104
2.00											95.2237

[illegible] of different
[illegible] $Q =$ [illegible]

Depth [illegible]	[illegible] weir	[illegible] weir	[illegible] weir	[illegible] weir	[illegible] weir	[illegible] weir	[illegible] weir	[illegible] weir	[illegible] weir	15-foot weir.	20-foot weir.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Acre-feet.	Acre-feet.	Acre-feet.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0050 –	0.0056 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.0142 –	.0157 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.0259 –	.0289 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.0407 –	.0445 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.0560 –	.0622 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.0736 –	.0818 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.0925 –	.1031 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.1133 –	.1259 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.1352 –	.1502 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.1584 –	.1760 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.1827 –	.2030 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.2062 –	.2313 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.2347 –	.2608 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.2625 –	.2915 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.2910 –	.3233 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.3216 –	.3561 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.3516 –	.3900 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.3823 –	.4250 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.4148 –	.4609 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.4480 –	.4977 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.4820 –	.5355 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.5168 –	.5742 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.5524 –	.6138 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.5886 –	.6543 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.6250 –	.6956 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.6640 –	.7377 +
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.7026 –	.7807 +
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.7430 –	.8245 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.7821 –	.8690 +
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.8229 –	.9144 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.8644 –	.9605 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.9066 –	1.0073 +
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.9494 –	1.0549 +
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.9929 –	1.1032 +
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.0370 –	1.1523 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.7212	[illegible]	[illegible]	1.0818 –	1.2020 –
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.7514 –	[illegible]	[illegible]	1.1272 –	1.2524 +
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.7822 –	[illegible]	[illegible]	1.1782 –	1.3035 +
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.8132 –	[illegible]	[illegible]	1.2198 –	1.3553 +
.40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.8447	.9854 –	[illegible]	1.2670 +	1.4078 –
.41	.1161	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.8765 –	1.0226 –	1.1687 –	1.3148 +	1.4609 +
.42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.9088 –	1.0603	1.2117 –	1.3632 +	1.5147 –
.43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.9415	1.0984	1.2553	1.4122 –	1.5691 –
.44	.1324	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.9745	1.1369	1.2993 –	1.4617 +	1.6241 +
.45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.0079	1.1759	1.3439 –	1.5118 +	1.6798 +
.46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.0417	1.2153	1.3889 –	1.5625 +	1.7361 +
.47	.1493	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.0758 –	1.2551 +	1.4344 –	1.6137 +	1.7930 +
.48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.1103 –	1.2954 +	1.4805	1.6655 +	1.8506 –
.49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.1452	1.3361	1.5270 –	1.7178 +	1.9087 +
.50	[illegible]	[illegible]	[illegible]	[illegible]	.7870	[illegible]	1.1805	1.3772 +	1.5739 –	1.7707 –	1.9674 +
.51		[illegible]	[illegible]	[illegible]	.8107	[illegible]	1.2160 –	1.4187 +	1.6214 –	1.8241 –	2.0267 +
.52		[illegible]	.4153	[illegible]	.8347	[illegible]	1.2520	1.4607	1.6693 +	1.8780 –	2.0867 –
.53		[illegible]	[illegible]	[illegible]	.8589	[illegible]	1.2883	1.5030	1.7177 –	1.9324 +	2.1471 +
.54		[illegible]	.4416	[illegible]	.8833	[illegible]	1.3249 –	1.5457 +	1.7665 +	1.9874 –	2.2082 –
.55		[illegible]	[illegible]	[illegible]	.9079	[illegible]	1.3619	1.5889	1.8158 –	2.0428 +	2.2698 +
.56		[illegible]	[illegible]	[illegible]	.9328	1.1660	1.3992	1.6324	1.8656 –	2.0988 –	2.3320 –
.57		[illegible]	.4790	[illegible]	.9579	[illegible]	1.4368 +	1.6763 +	1.9158 –	2.1553 –	2.3917 +
.58		[illegible]	.4916	[illegible]	.9832	1.2290	1.4748 +	1.7206 +	1.9664 +	2.2122 +	2.4580 +
.59		[illegible]	.5044	[illegible]	1.0087	[illegible]	1.5131 +	1.7653 +	2.0175	2.2697 –	2.5219 –
.60		[illegible]	.5173	[illegible]	1.0345	1.2931	1.5518	1.8104 –	2.0690 +	2.3276 +	2.5863 –
.61		[illegible]	.5302 +	.7954	1.0605	1.3256	1.5907 +	1.8558 +	2.1209 +	2.3861 –	2.6512 –
.62		[illegible]	.5433 +	[illegible]	1.0867	1.3583 +	1.6300 +	1.9016 +	2.1733 +	2.4450 –	2.7166 +
.63		.4171	.5565 +	.8348	1.1131	1.3913 +	1.6696	1.9178 +	2.2261 +	2.5044 –	2.7826 +
.64		.4271	.5698 +	.8547 +	1.1397	1.4246	1.7095	1.9944 +	2.2793 +	2.5642 +	2.8491 +
.65		.4374 +	.5832 +	.8749	1.1665	1.4581	1.7497 +	2.0413 +	2.3329 +	2.6246 –	2.9162 –
.66		.4476	.5967 +	.8951 +	1.1935	1.4919	1.7902 +	2.0886 +	2.3870	2.6854 –	2.9837 +
.67		.4578	.6104	.9155 +	1.2207 +	1.5259	1.8311	2.1363	2.4414 +	2.7466 +	3.0518 +
.68		.4681	.6241	.9361 +	1.2482	1.5602	1.8722 +	2.1843	2.4963 +	2.8083 +	3.1201 –
.69		.4784 +	.6379	.9568 +	1.2758	1.5947 +	1.9137	2.2326 +	2.5516	2.8705 +	3.1895 –
.70		.4889	.6518 +	.9777 +	1.3036 +	1.6295 +	1.9554 +	2.2813 +	2.6072 +	2.9331 +	3.2591 –
.71		.4994	.6658 +	.9987 +	1.3317	1.6646	1.9975	2.3304	2.6633 +	2.9962 +	3.3291 +
.72		.5100	.6799 +	1.0199 +	1.3599	1.6999	2.0398 +	2.3798 +	2.7198 –	3.0598 –	3.3997 +
.73		.5206 +	.6942	1.0412 +	1.3883 +	1.7354	2.0825	2.4296	2.7766 +	3.1237 +	3.4708 –
.74		.5314	.7085	1.0627 +	1.4169 +	1.7712	2.1254 +	2.4796 +	2.8339 –	3.1881 +	3.5424 –
.75		.5422 –	.7229 –	1.0843 +	1.4458 –	1.8072 +	2.1686 +	2.5301 –	2.8915 +	3.2530 –	3.6144 +

TABLE 2.—*Discharges, in acre-feet for two-hour periods, of Cippoletti weirs of different lengths, computed from the formula* $Q=3.3\frac{2}{3}\ Lh^{\frac{3}{2}}$—Continued.

Depth of water on crest.	1-foot weir.	1¼-foot weir.	2-foot weir.	3-foot weir.	4-foot weir.	5-foot weir.	6-foot weir.	7-foot weir.	8-foot weir.	9-foot weir.	10-foot weir.
Feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
0.76	....	....	0.7374 –	1.1061 –	1.4748 –	1.8435 –	2.2122 –	2.5809 –	2.9495 +	3.3182 +	3.6869 +
.77	....	....	.7520 –	1.1280 –	1.5040 –	1.8800 –	2.2560 –	2.6320 –	3.0080 –	3.3839 +	3.7599 +
.78	....	....	.7667 –	1.1500 +	1.5334 –	1.9167 +	2.3001 –	2.6834 –	3.0667 +	3.4501 –	3.8334 +
.79	....	....	.7815 –	1.1722 +	1.5630 –	1.9537 –	2.3444 +	2.7352 –	3.1259 +	3.5166 +	3.9074 –
.80	....	....	.7964 –	1.1945 +	1.5927 +	1.9909 +	2.3891 –	2.7873 –	3.1854 +	3.5836 +	3.9818 +
.81	....	....	.8113 +	1.2170 +	1.6227 –	2.0283 +	2.4340 +	2.8397 –	3.2454 –	3.6510 +	4.0567 –
.82	....	....	.8264 +	1.2396 +	1.6528 +	2.0660 +	2.4792 +	2.8924 +	3.3056 +	3.7188 +	4.1321 –
.83	....	....	.8416 –	1.2624 –	1.6831 +	2.1039 +	2.5247 +	2.9455 +	3.3663 –	3.7871 –	4.2079 –
.84	....	....	.8568 +	1.2852 +	1.7137 –	2.1421 –	2.5705 –	2.9989 –	3.4273 +	3.8557 +	4.2841 +
.85	....	....	.8722 –	1.3083 –	1.7443 +	2.1804 +	2.6165 +	3.0526 +	3.4887 –	3.9248 –	4.3609 –
.86	....	....	.8876 +	1.3314 +	1.7752 +	2.2190 +	2.6628 +	3.1066 +	3.5504 +	3.9942 +	4.4381 –
.87	....	....	.9031 +	1.3547 +	1.8063 –	2.2578 +	2.7094 +	3.1610 –	3.6125 +	4.0641 +	4.5157 –
.88	....	....	.9188 –	1.3781 +	1.8375 +	2.2969 –	2.7563 –	3.2156 +	3.6750 +	4.1344 –	4.5938 –
.89	....	....	.9345 –	1.4017 –	1.8689 +	2.3361 +	2.8034 –	3.2706 +	3.7378 +	4.2051 –	4.6723 –
.90	....	....	.9503 –	1.4254 –	1.9005 +	2.3756 +	2.8508 –	3.3259 –	3.8010 +	4.2761 +	4.7513 –
.91	....	....	.9661 +	1.4492 –	1.9323 –	2.4153 +	2.8984 –	3.3815 –	3.8645 +	4.3476 –	4.8307 –
.92	....	....	.9821 +	1.4732 –	1.9642 +	2.4553 –	2.9463 +	3.4371 –	3.9284 +	4.4195 –	4.9105 +
.93	....	....	.9982 –	1.4972 +	1.9963 +	2.4954 –	2.9945 –	3.4936 –	3.9926 +	4.4917 +	4.9908 –
.94	....	....	1.0143 +	1.5215 –	2.0286 +	2.5358 –	3.0429 +	3.5501 –	4.0572 +	4.5644 –	5.0715 +
.95	....	....	1.0305 +	1.5458 –	2.0611 –	2.5763 +	3.0916 –	3.6069 –	4.1221 +	4.6374 –	5.1526 +
.96	....	....	1.0468 +	1.5703 –	2.0937 –	2.6171 +	3.1405 +	3.6639 +	4.1874 –	4.7108 –	5.2342 +
.97	....	....	1.0632 +	1.5949 –	2.1265 –	2.6581 +	3.1897 +	3.7213 +	4.2530 –	4.7846 –	5.3162 +
.98	....	....	1.0797 +	1.6196 –	2.1595 –	2.6993 +	3.2392 –	3.7790 +	4.3189 +	4.8588 –	5.3986 +
.99	....	....	1.0963 –	1.6444 +	2.1926 –	2.7407 +	3.2889 –	3.8370 +	4.3852 –	4.9333 +	5.4815 –
1.00	....	....	1.1129 +	1.6694 +	2.2259 –	2.7824 –	3.3388 +	3.8953 +	4.4518 –	5.0083 –	5.5647 +
1.01	....	....	....	....	....	....	3.3891 –	3.9539 –	4.5187 +	5.0836 –	5.6484 +
1.02	....	....	....	....	....	....	3.4395 +	4.0128 –	4.5860 +	5.1593 –	5.7325 +
1.03	....	....	....	....	....	....	3.4902 +	4.0719 +	4.6536 +	5.2353 +	5.8170 +
1.04	....	....	....	....	....	....	3.5412 –	4.1314 –	4.7216 –	5.3117 +	5.9019 +
1.05	....	....	....	....	....	....	3.5921 –	4.1911 –	4.7898 +	5.3886 –	5.9873 –
1.06	....	....	....	....	....	....	3.6438 +	4.2511 +	4.8584 +	5.4657 +	6.0730 +
1.07	....	....	....	....	....	....	3.6955 –	4.3114 +	4.9273 +	5.5432 +	6.1591 +
1.08	....	....	....	....	....	....	3.7474 +	4.3720 –	4.9966 –	5.6211 +	6.2457 –
1.09	....	....	....	....	....	....	3.7996 –	4.4328 +	5.0661 +	5.6994 –	6.3326 +
1.10	....	....	....	....	....	....	3.8520 –	4.4940 –	5.1360 –	5.7780 –	6.4200 –
1.11	....	....	....	....	....	....	3.9046 +	4.5554 +	5.2062 –	5.8570 –	6.5077 +
1.12	....	....	....	....	....	....	3.9575 +	4.6171 +	5.2767 –	5.9363 –	6.5959 –
1.13	....	....	....	....	....	....	4.0106 +	4.6791 –	5.3475 +	6.0160 –	6.6844 –
1.14	....	....	....	....	....	....	4.0640 –	4.7413 +	5.4187 –	6.0960 –	6.7733 +
1.15	....	....	....	....	....	....	4.1176 –	4.8039 –	5.4901 +	6.1764 –	6.8626 +
1.16	....	....	....	....	....	....	4.1714 +	4.8666 +	5.5619 –	6.2571 +	6.9524 –
1.17	....	....	....	....	....	....	4.2255 –	4.9297 +	5.6340 –	6.3382 +	7.0424 +
1.18	....	....	....	....	....	....	4.2798 –	4.9930 +	5.7063 +	6.4196 +	7.1329 +
1.19	....	....	....	....	....	....	4.3343 –	5.0567 –	5.7790 +	6.5014 +	7.2238 –
1.20	....	....	....	....	....	....	4.3890 +	5.1205 +	5.8520 +	6.5835 +	7.3150 +
1.21	....	....	....	....	....	....	....	5.1847 –	5.9253 +	6.6660 –	7.4067 –
1.22	....	....	....	....	....	....	....	5.2491 –	5.9989 +	6.7488 +	7.4987 –
1.23	....	....	....	....	....	....	....	5.3137 +	6.0728 +	6.8320 –	7.5911 –
1.24	....	....	....	....	....	....	....	5.3787 –	6.1471 –	6.9154 +	7.6838 +
1.25	....	....	....	....	....	....	....	5.4439 –	6.2216 –	6.9993 –	7.7770 –
1.26	....	....	....	....	....	....	....	5.5093 +	6.2964 –	7.0834 +	7.8705 –
1.27	....	....	....	....	....	....	....	5.5750 +	6.3715 –	7.1679 +	7.9643 +
1.28	....	....	....	....	....	....	....	5.6410 +	6.4469 –	7.2527 +	8.0586 +
1.29	....	....	....	....	....	....	....	5.7073 –	6.5226 –	7.3379 –	8.1532 +
1.30	....	....	....	....	....	....	....	5.7737 +	6.5986 –	7.4234 –	8.2482 +
1.31	....	....	....	....	....	....	....	5.8405 –	6.6749 –	7.5092 +	8.3436 –
1.32	....	....	....	....	....	....	....	5.9075 –	6.7514 +	7.5954 –	8.4393 –
1.33	....	....	....	....	....	....	....	5.9748 –	6.8283 –	7.6818 +	8.5354 –
1.34	....	....	....	....	....	....	....	6.0423 –	6.9054 +	7.7686 +	8.6318 +
1.35	....	....	....	....	....	....	....	6.1100 +	6.9829 –	7.8558 –	8.7286 +
1.36	....	....	....	....	....	....	....	6.1780 +	7.0606 +	7.9432 +	8.8258 –
1.37	....	....	....	....	....	....	....	6.2463 +	7.1386 +	8.0310 –	8.9233 +
1.38	....	....	....	....	....	....	....	6.3148 +	7.2169 +	8.1191 –	9.0212 –
1.39	....	....	....	....	....	....	....	6.3836 –	7.2955 +	8.2075 –	9.1194 +
1.40	....	....	....	....	....	....	....	6.4526	7.3744	8.2962	9.2180
1.41	....	....	....	....	....	....	....	....	7.4536 –	8.3852 +	9.3169 +
1.42	....	....	....	....	....	....	....	....	7.5330 –	8.4746 +	9.4162 +
1.43	....	....	....	....	....	....	....	....	7.6127 –	8.5643 –	9.5159 –
1.44	....	....	....	....	....	....	....	....	7.6927 –	8.6543 –	9.6159 –
1.45	....	....	....	....	....	....	....	....	7.7730 –	8.7446 –	9.7162 +
1.46	....	....	....	....	....	....	....	....	7.8535 +	8.8352 –	9.8169 –
1.47	....	....	....	....	....	....	....	....	7.9343 +	8.9261 +	9.9179 +
1.48	....	....	....	....	....	....	....	....	8.0154 +	9.0174 –	10.0193 –
1.49	....	....	....	....	....	....	....	....	8.0968 +	9.1089 +	10.1210 +
1.50	....	....	....	....	....	....	....	....	8.1785 –	9.2008 –	10.2231 –

TABLE 2.—*Discharge, in acre-feet for twenty-four-hour periods, of Cippoletti weirs of different lengths computed from the formula* $Q=3.367\ LD^{\frac{3}{2}}$—Continued.

Depth of water on crest.	1-foot weir.	1½-foot weir.	2-foot weir.	3-foot weir.	4-foot weir.	5-foot weir.	6-foot weir.	7-foot weir.	8-foot weir.	9-foot weir.	10-foot weir.
Feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1.51									8.2604−	9.2929−	10.3255−
1.52									8.3435−	9.3864−	10.4292+
1.53									8.4250−	9.4782−	10.5313−
1.54									8.5078−	9.5712+	10.6347+
1.55									8.5908−	9.6646−	10.7385−
1.56									8.6740−	9.7583−	10.8425−
1.57									8.7576−	9.8523−	10.9470−
1.58									8.8414−	9.9466−	11.0517+
1.59									8.9255−	10.0411+	11.1568+
1.60									9.0098−	10.1360−	11.2622+
1.61										10.2312−	11.3690−
1.62										10.3267−	11.4741−
1.63										10.4224+	11.5805−
1.64										10.5185−	11.6872−
1.65										10.6148−	11.7943−
1.66										10.7115−	11.9016+
1.67										10.8084−	12.0093+
1.68										10.9056−	12.1174−
1.69										11.0032−	12.2257+
1.70										11.1010−	12.3344+
1.71										11.1991−	12.4434−
1.72										11.2974−	12.5527+
1.73										11.3961−	12.6623+
1.74										11.4951−	12.7723−
1.75										11.5943−	12.8825+
1.76										11.6938−	12.9931+
1.77										11.7936−	13.1040+
1.78										11.8937+	13.2152+
1.79										11.9941	13.3267+
1.80										12.0947+	13.4386−
1.81											13.5507+
1.82											13.6632−
1.83											13.7759+
1.84											13.8890+
1.85											14.0024−
1.86											14.1161−
1.87											14.2301−
1.88											14.3444−
1.89											14.4590−
1.90											14.5739−
1.91											14.6891−
1.92											14.8046−
1.93											14.9204+
1.94											15.0365+
1.95											15.1529+
1.96											15.2696+
1.97											15.3866+
1.98											15.5040−
1.99											15.6216−
2.00											15.7396−

TABLE 3.—*Discharges, in cubic feet per second for two-hour periods, of rectangular weirs from 1 to 10 feet long, without end contractions, computed from the formula* $Q=3.33\ Lh^{\frac{3}{2}}$.

Depth of water on crest.	1-foot weir.	1½-foot weir.	2-foot weir.	3-foot weir.	4-foot weir.	5-foot weir.	6-foot weir.	7-foot weir.	8-foot weir.	9-foot weir.	10-foot weir.
Feet.	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*
0.01	0.0033+	0.0050−	0.0067−	0.0100−	0.0133+	0.01665	0.0200−	0.0233+	0.0266+	0.0300−	0.0333
.02	.0094+	.0141+	.0188+	.0283−	.0377−	.0471−	.0565+	.0659+	.0753+	.0848−	.0942−
.03	.0173+	.0260−	.0346+	.0519+	.0692+	.0865+	.1038+	.1211+	.1384+	.1557+	.1730+
.04	.0266+	.0400−	.0533−	.0799+	.1066−	.1332	.1598+	.1865−	.2131+	.2398−	.2664
.05	.0372+	.0558+	.0745−	.1117−	.1489+	.1862−	.2234−	.2606+	.2978+	.3351−	.3723+
.06	.0489+	.0734+	.0979−	.1468+	.1958−	.2447+	.2936+	.3426−	.3915+	.4405−	.4894+
.07	.0617−	.0925+	.1233+	.1850+	.2467−	.3084−	.3700+	.4317+	.4934−	.5551−	.6167+
.08	.0753+	.1130+	.1507−	.2260+	.3014−	.3767+	.4521−	.5274+	.6028−	.6781+	.7535−
.09	.0899+	.1349−	.1798+	.2697+	.3596+	.44955	.5395−	.6294−	.7193−	.8092−	.8991
.10	.1053+	.1580−	.2106+	.3159+	.4212+	.5265+	.6318+	.7371+	.8424+	.9477+	1.0530+
.11	.1215−	.1822+	.2430−	.3645−	.4860−	.6074+	.7289+	.8504+	.9719+	1.0934−	1.2149−
.12	.1384+	.2076+	.2769−	.4153−	.5537+	.6921+	.8306−	.9690−	1.1074+	1.2458+	1.3843−
.13	.1561−	.2341+	.3122−	.4683−	.6243+	.7804+	.9365+	1.0926−	1.2487−	1.4048−	1.5608+
.14	.1744+	.2617−	.3489−	.5233+	.6977+	.8722−	1.0466+	1.2211−	1.3955−	1.5699+	1.7444−
.15	.1935−	.2902−	.3869+	.5804−	.7738+	.9673−	1.1607+	1.3542−	1.5476+	1.7411−	1.9346−
.16	.2131+	.3197−	.4262+	.6394−	.8525−	1.0656	1.2787+	1.4918+	1.7050−	1.9181−	2.1312
.17	.2334+	.3501+	.4668+	.7002+	.9336+	1.1670+	1.4005−	1.6339−	1.8673−	2.1007−	2.3341−
.18	.2543+	.3815−	.5086+	.7629+	1.0172+	1.2715+	1.5258+	1.7801+	2.0344+	2.2887+	2.5430+
.19	.2758−	.4137−	.5516−	.8274−	1.1032−	1.3789+	1.6547+	1.9305+	2.2063+	2.4821−	2.7579−
.20	.2978+	.4468−	.5957−	.8935+	1.1914−	1.4892+	1.7871−	2.0849+	2.3828−	2.6806−	2.9784+
.21	.3205−	.4807−	.6409+	.9614−	1.2818+	1.6023−	1.9228−	2.2432+	2.5637−	2.8841+	3.2046−
.22	.3436+	.5154+	.7872+	1.0309−	1.3745−	1.7181−	2.0617+	2.4053+	2.7490−	3.0926−	3.4362−
.23	.3673+	.5510−	.7346+	1.1019+	1.4693−	1.8366−	2.2039−	2.5712−	2.9385+	3.3058+	3.6731+
.24	.3915+	.5873−	.7831−	1.1746−	1.5661+	1.9576+	2.3492−	2.7407−	3.1322+	3.5237+	3.9153−
.25	.41625	.6244−	.8325	1.24875	1.6650	2.08125	2.4975	2.91375	3.3300	3.74625	4.1625
.26	.4415−	.6622+	.8829+	1.3244+	1.7659−	2.2074−	2.6488+	3.0903+	3.5318−	3.9733−	4.4147+
.27	.4672−	.7008−	.9344−	1.4016−	1.8687+	2.3359+	2.8031+	3.2703+	3.7375−	4.2047−	4.6719−
.28	.4934−	.7401−	.9868−	1.4801+	1.9735+	2.4669−	2.9603−	3.4537−	3.9470+	4.4404+	4.9338−
.29	.5200+	.7801−	1.0401−	1.5601+	2.0802−	2.6002+	3.1203−	3.6403+	4.1604−	4.6804+	5.2005−
.30	.5472−	.8208−	1.0943+	1.6415+	2.1887−	2.7359−	3.2830+	3.8302+	4.3774−	4.9246−	5.4717+
.31	.5748−	.8621+	1.1495+	1.7243−	2.2990+	2.8738+	3.4486−	4.0233+	4.5981−	5.1728+	5.7476+
.32	.6028−	.9042−	1.2056−	1.8084−	2.4112−	3.0140−	3.6168−	4.2196−	4.8224−	5.4251+	6.0279+
.33	.6313−	.9469+	1.2625+	1.8938+	2.5251−	3.1563+	3.7876+	4.4189−	5.0502−	5.6814+	6.3127−
.34	.6602−	.9903−	1.3201−	1.9805+	2.6407+	3.3009+	3.9611−	4.6213−	5.2814+	5.9416+	6.6018+
.35	.6895+	1.0343−	1.3790+	2.0686−	2.7581−	3.4476−	4.1371+	4.8266+	5.5162−	6.2057−	6.8952−
.36	.7193−	1.0789+	1.4386−	2.1578+	2.8771+	3.5964	4.3157−	5.0350−	5.7542+	6.4735+	7.1928
.37	.7495−	1.1242−	1.4989+	2.2484−	2.9978+	3.7473−	4.4967+	5.2462+	5.9957−	6.7451+	7.4946−
.38	.7800+	1.1701−	1.5601−	2.3401+	3.1202−	3.9002+	4.6803−	5.4603+	6.2404−	7.0204+	7.8004+
.39	.8110+	1.2166−	1.6221−	2.4331+	3.2442−	4.0552−	4.8662+	5.6773−	6.4883+	7.2993+	8.1104−
.40	.8424+	1.2636+	1.6849−	2.5273−	3.3697+	4.2122−	5.0546−	5.8970+	6.7394+	7.5819−	8.4243+
.41	.8742+	1.3113+	1.7484+	2.6227−	3.4969−	4.3711−	5.2453+	6.1195+	6.9937+	7.8680−	8.7422−
.42	.9064−	1.3596−	1.8128−	2.7192−	3.6256−	4.5320−	5.4384−	6.3448−	7.2512−	8.1576−	9.0640−
.43	.9390−	1.4084+	1.8779+	2.8169−	3.7558+	4.6948−	5.6338−	6.5727+	7.5117−	8.4506+	9.3896−
.44	.9719+	1.4579−	1.9438+	2.9157+	3.8876+	4.8595+	5.8314+	6.8033+	7.7752+	8.7471+	9.7190+
.45	1.0052+	1.5078+	2.0104+	3.0157−	4.0209−	5.0261+	6.0313+	7.0366−	8.0418−	9.0470+	10.0522+
.46	1.0389+	1.5584−	2.0778+	3.1168−	4.1557−	5.1946−	6.2335+	7.2724+	8.3113+	9.3503−	10.3892−
.47	1.0730−	1.6095−	2.1460−	3.2189+	4.2919+	5.3649−	6.4379−	7.5108+	8.5838+	9.6568+	10.7298−
.48	1.1074+	1.6611+	2.2148+	3.3222+	4.4296+	5.5370+	6.6444+	7.7518+	8.8592+	9.9666+	11.0740+
.49	1.1422−	1.7133−	2.2844−	3.4266−	4.5688−	5.71095	6.8531+	7.9953+	9.1375+	10.2797+	11.4219
.50	1.1773−	1.7660−	2.3547−	3.5320−	4.7093+	5.8867−	7.0640−	8.2413+	9.4187−	10.5960−	11.7733+
.51	....	1.8192+	2.4257−	3.6385−	4.8513+	6.0641+	7.2770−	8.4898+	9.7026+	10.9155−	12.1283−
.52	....	1.8730+	2.4973+	3.7460+	4.9947−	6.2434−	7.4920+	8.7407+	9.9894−	11.2381−	12.4867+
.53	....	1.9273−	2.5697+	3.8546−	5.1395−	6.4243+	7.7092−	8.9941−	10.2789+	11.5638−	12.8487−
.54	....	1.9821+	2.6428+	3.9642+	5.2856+	6.6070+	7.9284+	9.2498+	10.5712+	11.8926+	13.2140+
.55	....	2.0374+	2.7166−	4.0748+	5.4331+	6.7914−	8.1497−	9.5079+	10.8662+	12.2245−	13.5828−
.56	....	2.0932+	2.7910−	4.1865−	5.5820−	6.9774+	8.3729+	9.7684+	11.1639+	12.5594−	13.9549−
.57	....	2.1496−	2.8661−	4.2991+	5.7321+	7.1652−	8.5982+	10.0312+	11.4643−	12.8973+	14.3303+
.58	....	2.2064−	2.9418+	4.4127+	5.8836+	7.3546+	8.8255−	10.2964−	11.7673−	13.2382−	14.7091+
.59	....	2.2637−	3.0182+	4.5273+	6.0365−	7.5456−	9.0547−	10.5638+	12.0729+	13.5820+	15.0911+
.60	....	2.3215−	3.0953−	4.6429+	6.1906−	7.7382+	9.2859−	10.8335+	12.3812−	13.9288−	15.4764+
.61	....	2.3797+	3.1730−	4.7595−	6.3460−	7.9325−	9.5190−	11.1055−	12.6920−	14.2785+	15.8650−
.62	....	2.4385+	3.2513+	4.8770+	6.5027−	8.1283+	9.7540+	11.3797−	13.0053+	14.6310+	16.2567−
.63	....	2.4977+	3.3303+	4.9955−	6.6606+	8.3258−	9.9909+	11.6561−	13.3213−	14.9864+	16.6516−
.64	....	2.5574+	3.4099+	5.1149−	6.8198+	8.5248	10.2298−	11.9347+	13.6397−	15.3446+	17.0496
.65	....	2.6176+	3.4902−	5.2352+	6.9803+	8.7254−	10.4705−	12.2155+	13.9606+	15.7057−	17.4508−
.66	....	2.6783−	3.5710+	5.3565+	7.1420+	8.9275+	10.7130+	12.4985+	14.2840+	16.0695+	17.8550+
.67	....	2.7394−	3.6525−	5.4787+	7.3049+	9.1312−	10.9574+	12.7836+	14.6099−	16.4361+	18.2623+
.68	....	2.8009+	3.7345+	5.6018+	7.4691−	9.3364−	11.2036+	13.0709+	14.9382−	16.8054+	18.6727+
.69	....	2.8629+	3.8172+	5.7258+	7.6345−	9.5431−	11.4517−	13.3603−	15.2689+	17.1775+	19.0861+
.70	....	2.9254−	3.9005+	5.8508−	7.8010+	9.7513−	11.7015+	13.6518−	15.6020+	17.5523−	19.5025+
.71	....	2.9883−	3.9844−	5.9766−	7.9688−	9.9610−	11.9532−	13.9454−	15.9376−	17.9298−	19.9219+
.72	....	3.0516+	4.0689−	6.1033−	8.1377+	10.1722−	12.2066−	14.2410+	16.2754+	18.3099−	20.3443+

TABLE 3.—*Discharges, in cubic feet per second for two-hour periods, of rectangular weirs from 1 to 10 feet long, without end contractions, computed from the formula* $Q=3.33\ Lh^{\frac{3}{2}}$—Continued.

Depth of water on crest.	1-foot weir.	1½-foot weir.	2-foot weir.	3-foot weir.	4-foot weir.	5-foot weir.	6-foot weir.	7-foot weir.	8-foot weir.	9-foot weir.	10-foot weir.
Feet.	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*
0.73		3.1154-	4.1539+	6.2309	8.3078+	10.3848+	12.4618-	14.5387+	16.6157-	18.6927-	20.7696+
.74		3.1797	4.2396+	6.3594	8.4791-	10.5989-	12.7187+	14.8385-	16.9583-	19.0781-	21.1978+
.75		3.2443-	4.3258	6.4887	8.6516-	10.8145-	12.9774-	15.1403-	17.3032-	19.4661-	21.6290-
.76			4.4126	6.6189-	8.8252+	11.0315+	13.2378-	15.4441-	17.6504+	19.8567+	22.0630+
.77			4.5000	6.7500	9.0000	11.2499-	13.4999+	15.7499+	17.9999+	20.2499-	22.4999-
.78			4.5879-	6.8819-	9.1758+	11.4698+	13.7638	16.0577+	18.3517-	20.6457-	22.9396+
.79			4.6764-	7.0147	9.3529	11.6911	14.0293+	16.3675+	18.7057+	21.0440-	23.3822-
.80			4.7655-	7.1483	9.5310+	11.9138	14.2965+	16.6793-	19.0620+	21.4448-	23.8275+
.81			4.8551-	7.2827-	9.7103	12.1378+	14.5654+	16.9930	19.4206-	21.8481+	24.2757
.82			4.9453-	7.4180	9.8907	12.3633-	14.8360-	17.3086+	19.7813+	22.2540-	24.7266+
.83			5.0361	7.5541	10.0721+	12.5902	15.1082-	17.6262+	20.1443-	22.6623-	25.1803+
.84			5.1274	7.6910+	10.2547+	12.8184-	15.3821	17.9457-	20.5094+	23.0731-	25.6368-
.85			5.2192	7.8288	10.4384	13.0481	15.6576-	18.2671+	20.8767+	23.4863+	26.0959+
.86			5.3116	7.9673+	10.6231+	13.2789	15.9347	18.5905-	21.2462+	23.9020+	26.5578-
.87			5.4045	8.1067+	10.8089+	13.5112	16.2134-	18.9156-	21.6179-	24.3201+	27.0223+
.88			5.4979+	8.2469	10.9958+	13.7448	16.4938	19.2427+	21.9917-	24.7406+	27.4896-
.89			5.5919-	8.3878+	11.1838	13.9797-	16.7757	19.5716-	22.3676-	25.1635+	27.9595-
.90			5.6864+	8.5296+	11.3728+	14.2160-	17.0592-	19.9024-	22.7456+	25.5888+	28.4320+
.91			5.7814+	8.6722	11.5629	14.4536-	17.3443-	20.2351	23.1258-	26.0165-	28.9072+
.92			5.8770+	8.8155-	11.7540-	14.6925-	17.6310-	20.5695+	23.5080+	26.4465+	29.3850+
.93			5.9731-	8.9596-	11.9462	14.9327-	17.9193	20.9058	23.8923+	26.8789-	29.8654+
.94			6.0697	9.1045+	12.1394	15.1742-	18.2090-	21.2439	24.2787+	27.3136-	30.3484+
.95			6.1668-	9.2502	12.3336	15.4170	18.5004	21.5838-	24.6672-	27.7506-	30.8340-
.96			6.2644+	9.3966+	12.5288-	15.6611	18.7933	21.9255	25.0577-	28.1899+	31.3221+
.97			6.3626-	9.5438+	12.7251-	15.9064	19.0877	22.2690-	25.4502+	28.6315+	31.8128-
.98			6.4612+	9.6918+	12.9224-	16.1530-	19.3836+	22.6142-	25.8448+	29.0754+	32.3060+
.99			6.5604	9.8405+	13.1207-	16.4009-	19.6811	22.9612-	26.2414+	29.5216-	32.8018-
1.00			6.6600	9.9900	13.3200	16.6500	19.9800	23.3100	26.6400	29.9700	33.3000
1.01							20.2804+	23.6605+	27.0406	30.4207-	33.8007+
1.02							20.5824	24.0128	27.4432	30.8736-	34.3040-
1.03							20.8858+	24.3668	27.8477+	31.3287+	34.8097-
1.04							21.1907+	24.7225	28.2543	31.7861-	35.3178+
1.05							21.4971	25.0799-	28.6628	32.2456+	35.8285-
1.06							21.8049+	25.4391-	29.0732+	32.7074-	36.3415+
1.07							22.1142	25.7999	29.4856	33.1713-	36.8570-
1.08							22.4249+	26.1624-	29.8999+	33.6374-	37.3749-
1.09							22.7371+	26.5266+	30.3161-	34.1057-	37.8952-
1.10							23.0507-	26.8925-	30.7343	34.5761-	38.4179-
1.11							23.3658-	27.2601	31.1543+	35.0486+	38.9429+
1.12							23.6822-	27.6293	31.5763+	35.5233+	39.4704-
1.13							24.0001+	28.0001+	32.0001+	36.0002-	40.0002-
1.14							24.3194	28.3726+	32.4259	36.4791-	40.5323+
1.15							24.6401	28.7468	32.8534+	36.9601+	41.0668+
1.16							24.9622	29.1225+	33.2829+	37.4433-	41.6036+
1.17							25.2857	29.4999+	33.7142+	37.9285-	42.1428-
1.18							25.6105+	29.8789-	34.1474	38.4158-	42.6842+
1.19							25.9368	30.2596	34.5824	38.9052-	43.2280-
1.20							26.2644	30.6418	35.0192	39.3966-	43.7740-
1.21								31.0256+	35.4578-	39.8901	44.3223
1.22								31.4110+	35.8983+	40.3856	44.8729-
1.23								31.7980+	36.3406	40.8832	45.4257+
1.24								32.1866	36.7847	41.3827+	45.9808+
1.25								32.5767+	37.2305+	41.8843+	46.5382-
1.26								32.9684-	37.6782	42.3880-	47.0977+
1.27								33.3617	38.1276-	42.8936	47.6595+
1.28								33.7565	38.5788+	43.4012	48.2236-
1.29								34.1528+	39.0318+	43.9108	48.7898-
1.30								34.5507+	39.4866-	44.4224-	49.3582-
1.31								34.9502	39.9430+	44.9359+	49.9288+
1.32								35.3511+	40.4013	45.4514+	50.5016-
1.33								35.7536	40.8613	45.9689+	51.0766-
1.34								36.1576	41.3230-	46.4883+	51.6537-
1.35								36.5631	41.7864-	47.0097-	52.2330-
1.36								36.9701+	42.2515+	47.5330-	52.8144+
1.37								37.3786-	42.7184+	48.0582+	53.3980+
1.38								37.7886+	43.1870	48.5854-	53.9837+
1.39								38.2001-	43.6573	49.1144+	54.5716-
1.40								38.6131	44.1292+	49.6454-	55.1615+
1.41									44.6029	50.1782+	55.7536-
1.42									45.0782+	50.7130-	56.3478-

TABLE 3.—*Discharges, in cubic feet per second for two-hour periods, of rectangular weirs from 1 to 10 feet long, without end contractions, computed from the formula* $Q=3.33\,Lh^{\frac{3}{2}}$—Continued.

Depth of water on crest.	1-foot weir.	1½-foot weir.	2-foot weir.	3-foot weir.	4-foot weir.	5-foot weir.	6-foot weir.	7-foot weir.	8-foot weir.	9-foot weir.	10-foot weir.
Feet.	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*
1.43									45.5552+	51.2496+	56.9440+
1.44									46.0339+	51.7882−	57.5424
1.45									46.5143−	52.3286−	58.1428+
1.46									46.9963−	52.8708+	58.7454−
1.47									47.4799+	53.4149+	59.3499+
1.48									47.9653−	53.9609+	59.9566−
1.49									48.4522+	54.5087+	60.5653−
1.50									48.9408+	55.0584+	61.1760+
1.51									49.4310+	55.6099+	61.7888−
1.52									49.9229−	56.1632+	62.4036−
1.53									50.4163+	56.7184−	63.0204+
1.54									50.9114+	57.2754−	63.6393−
1.55									51.4081+	57.8341+	64.2602−
1.56									51.9064+	58.3947+	64.8830+
1.57									52.4063+	58.9571+	65.5079+
1.58									52.9078+	59.5213−	66.1348−
1.59									53.4109+	60.0873−	66.7636+
1.60									53.9156−	60.6550+	67.3945−
1.61										61.2245+	68.0273−
1.62										61.7958+	68.6620+
1.63										62.3689+	69.2988−
1.64										62.9437+	69.9375−
1.65										63.5203+	70.5781+
1.66										64.0986+	71.2207+
1.67										64.6787+	71.8652+
1.68										65.2605+	72.5117+
1.69										65.8441−	73.1601
1.70										66.4294−	73.8104+
1.71										67.0164−	74.4626+
1.72										67.6051−	75.1168−
1.73										68.1955+	75.7728+
1.74										68.7877−	76.4307+
1.75										69.3815+	77.0906−
1.76										69.9771−	77.7523−
1.77										70.5743+	78.4159+
1.78										71.1732+	79.0814−
1.79										71.7739−	79.7487+
1.80										72.3762−	80.4179+
1.81											81.0890+
1.82											81.7620−
1.83											82.4368−
1.84											83.1134−
1.85											83.7919−
1.86											84.4722−
1.87											85.1543+
1.88											85.8383−
1.89											86.5241−
1.90											87.2117−
1.91											87.9011−
1.92											88.5923+
1.93											89.2853+
1.94											89.9802−
1.95											90.6768−
1.96											91.3752
1.97											92.0754−
1.98											92.7774−
1.99											93.4811+
2.00											94.1866+

[illegible] from 1 to 10 [illegible] $=3.33\ LH^{\frac{3}{2}}$.

Head in feet.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Nine-foot weir.	Ten-foot weir.
Feet.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Acre-feet.	Acre-feet.	Acre-feet.
.01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0050−	0.0055−
.02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.0140−	.0156−
.03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.0257−	.0286+
.04	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.0396−	.0440+
.05	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.0554	.0615−
.06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.0728−	.0809−
.07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.0917−	.1019+
.08	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.1121−	.1245+
.09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.1338−	.1486−
.10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.1567−	.1741−
.11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.1807−	.2009+
.12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.2059−	.2288+
.13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.2322−	.2580−
.14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.2595−	.2883+
.15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.2878−	.3196−
.16	.0352	.0528	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.3170−	.3523−
.17	.0386	.0579	.0772	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.3472−	.3858+
.18	.0420	.0630	.0841	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.3783−	.4203+
.19	.0456	.0683	.0911	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.4103−	.4556+
.20	.0492	.0738	.0985	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.4431−	.4923−
.21	.0530	.0795	.1059	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.4767−	.5297−
.22	.0568	.0852	.1136	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.4544	.5112	.5680−
.23	.0607	.0911	.1214	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.4857	.5464−	.6071−
.24	.0647	.0971	.1294	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.5177	.5824−	.6472−
.25	.0688	.1032	.1376	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.5504	.6192−	.6880+
.26	.0730	.1095	.1459	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.5838	.6567−	.7297+
.27	.0772	.1158	.1544	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.6178	.6950	.7722+
.28	.0816	.1223	.1631	.2447	[illegible]	[illegible]	[illegible]	[illegible]	.6524	.7340	.8155+
.29	.0860	.1289	.1719	.2579	[illegible]	[illegible]	[illegible]	[illegible]	.6877	.7736−	.8596−
.30	.0904	.1357	.1809	.2713	.3618	.4522	.5427	[illegible]	.7235	.8140	.9044+
.31	.0950	.1425	.1900	.2850	.3800	.4750	.5700	[illegible]	.7600	.8550−	.9500+
.32	.0996	.1495	.1993	.2989	.3986	.4982	.5978	[illegible]	.7971	.8967−	.9964−
.33	.1043	.1565	.2087	.3130	.4174	.5217	.6261	.7304	.8347	.9391	1.0434+
.34	.1091	.1637	.2182	.3274	.4365	.5456	.6547	[illegible]	.8730	.9821	1.0912+
.35	.1140	.1710	.2279	.3419	.4559	.5698	.6838	.7978	.9118	1.0257−	1.1397+
.36	.1189	.1783	.2378	.3567	.4756	.5944	.7133	.8322	.9511	1.0700−	1.1889−
.37	.1239	.1858	.2478	.3716	.4955	.6194	.7433	.8671	.9910	1.1149	1.2388−
.38	.1289	.1934	.2579	.3868	.5157	.6447	.7736	.9025	1.0315	1.1604	1.2893+
.39	.1341	.2011	.2681	.4022	.5362	.6703	.8044	.9384	1.0724	1.2065−	1.3406−
.40	.1392	.2089	.2785	.4177	.5570	.6962	.8355	.9747	1.1140	1.2532+	1.3924+
.41	.1445	.2167	.2890	.4335	.5780	.7225	.8670	1.0115	1.1560	1.3005−	1.4450−
.42	.1498	.2247	.2996	.4495	.5993	.7491	.8989	1.0487	1.1985	1.3484−	1.4982−
.43	.1552	.2328	.3104	.4656	.6208	.7760	.9312	1.0864	1.2416	1.3968	1.5520−
.44	.1606	.2410	.3213	.4819	.6426	.8032	.9639	1.1246	1.2852	1.4458+	1.6065−
.45	.1662	.2492	.3323	.4985	.6646	.8308	.9969	1.1631	1.3292	1.4954−	1.6615+
.46	.1717	.2576	.3434	.5152	.6869	.8586	1.0303	1.2021	1.3738	1.5455−	1.7172+
.47	.1774	.2660	.3547	.5321	.7094	.8868	1.0641	1.2415	1.4188	1.5962−	1.7735+
.48	.1830	.2746	.3661	.5491	.7322	.9152	1.0983	1.2813	1.4643	1.6474−	1.8304+
.49	.1888	.2832	.3776	.5664	.7552	.9440	1.1328	1.3215	1.5103	1.6991−	1.8879+
.50	.1946	.2919	.3892	.5838	.7784	.9730	1.1676	1.3622	1.5568	1.7514−	1.9460+
.51		.3007	.4009	.6014	.8019	1.0023	1.2028	1.4033	1.6037	1.8042+	2.0047−
.52		.3096	.4128	.6192	.8256	1.0320	1.2384	1.4447	1.6511	1.8575+	2.0639+
.53		.3186	.4247	.6371	.8495	1.0619	1.2742	1.4866	1.6990	1.9114−	2.1237+
.54		.3276	.4368	.6552	.8737	1.0921	1.3105	1.5289	1.7473	1.9657+	2.1841+
.55		.3368	.4490	.6735	.8980	1.1225	1.3471	1.5716	1.7961	2.0206−	2.2451−
.56		.3460	.4613	.6920	.9226	1.1533	1.3840	1.6146	1.8453	2.0759+	2.3066−
.57		.3553	.4737	.7106	.9475	1.1843	1.4212	1.6581	1.8949	2.1318−	2.3687−
.58		.3647	.4863	.7294	.9725	1.2156	1.4588	1.7019	1.9450	2.1881+	2.4313−
.59		.3742	.4989	.7483	.9978	1.2472	1.4966	1.7461	1.9955	2.2450	2.4944+
.60		.3837	.5116	.7674	1.0232	1.2790	1.5349	1.7907	2.0465	2.3023−	2.5581−
.61		.3933	.5245	.7867	1.0489	1.3112	1.5734	1.8356	2.0978	2.3601−	2.6223+
.62		.4031	.5374	.8061	1.0748	1.3436	1.6123	1.8809	2.1496	2.4183+	2.6871−
.63		.4128	.5505	.8257	1.1009	1.3762	1.6514	1.9266	2.2019	2.4771−	2.7523+
.64		.4227	.5636	.8454	1.1272	1.4091	1.6909	1.9727	2.2545	2.5363+	2.8181+
.65		.4327	.5769	.8653	1.1538	1.4422	1.7307	2.0191	2.3075	2.5960−	2.8844+
.66		.4427	.5902	.8854	1.1805	1.4756	1.7707	2.0659	2.3610	2.6561+	2.9512+
.67		.4528	.6037	.9056	1.2074	1.5093	1.8111	2.1130	2.4149	2.7167+	3.0186−
.68		.4630	.6173	.9259	1.2346	1.5432	1.8518	2.1605	2.4691	2.7778−	3.0864+
.69		.4732	.6309	.9464	1.2619	1.5774	1.8928	2.2083	2.5238	2.8393−	3.1547+
.70		.4835	.6447	.9671	1.2894	1.6118	1.9341	2.2565	2.5788	2.9012+	3.2236−
.71		.4939	.6586	.9879	1.3172	1.6464	1.9757	2.3050	2.6343	2.9636−	3.2929−
.72		.5044	.6725	1.0088	1.3451	1.6813	2.0176	2.3539	2.6902	3.0264+	3.3627−
.73		.5149	.6866	1.0299	1.3732	1.7165	2.0598	2.4031	2.7464	3.0897−	3.4330−
.74		.5256	.7008	1.0511	1.4015	1.7519	2.1023	2.4526	2.8030	3.1534−	3.5038−
.75		.5363−	.7150+	1.0725+	1.4300+	1.7875+	2.1450+	2.5025+	2.8600+	3.2175+	3.5750+

TABLE 4.—*Discharges, in acre-feet for two-hour periods, of rectangular weirs from 1 to 10 feet long, without end contractions, computed from the formula* $Q=3.33\ Lh^{\frac{3}{2}}$—Cont'd.

Depth of water on crest	1-foot weir	1½-foot weir	2-foot weir	3-foot weir	4-foot weir	5-foot weir	6-foot weir	7-foot weir	8-foot weir	9-foot weir.	10-foot weir.
Feet	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*	*Acre-feet*
0.76			0.7294–	1.0940+	1.4587+	1.8234	2.1881–	2.5527+	2.9174+	3.2821	3.6468
.77			.7438	1.1157	1.4876	1.8595	2.2314	2.6033	2.9752	3.3471	3.7190–
.78			.7583+	1.1375+	1.5167	1.8958+	2.2750+	2.6542–	3.0333	3.4125+	3.7917–
.79			.7730	1.1594+	1.5459+	1.9324+	2.3189	2.7054	3.0919–	3.4783+	3.8648+
.80			.7877	1.1815+	1.5754–	1.9692	2.3631	2.7569+	3.1507+	3.5446	3.9384+
.81			.8025+	1.2038	1.6051+	2.0063	2.4076+	2.8088	3.2100+	3.6113–	4.0125+
.82			.8174+	1.2261+	1.6348+	2.0435+	2.4522	2.8609+	3.2696+	3.6783+	4.0870+
.83			.8324	1.2486+	1.6648+	2.0810+	2.4972+	2.9134+	3.3296+	3.7458+	4.1620+
.84			.8475	1.2712+	1.6950	2.1187+	2.5425	2.9662+	3.3900	3.8137+	4.2375–
.85			.8627	1.2940+	1.7254–	2.1567	2.5880+	3.0194–	3.4507+	3.8820+	4.3134
.86			.8779	1.3169+	1.7559	2.1949	2.6338+	3.0728+	3.5118	3.9507+	4.3897+
.87			.8933+	1.3400–	1.7866+	2.2333	2.6799+	3.1266	3.5732+	4.0199	4.4665+
.88			.9087+	1.3631+	1.8175	2.2719	2.7262	3.1806+	3.6350–	4.0894–	4.5437+
.89			.9243	1.3864+	1.8486	2.3107	2.7729+	3.2350	3.6971+	4.1592	4.6214+
.90			.9399+	1.4099	1.8798+	2.3498–	2.8197+	3.2897	3.7596+	4.2296–	4.6995+
.91			.9556+	1.4334–	1.9112+	2.3890+	2.8668+	3.3446+	3.8224+	4.3002+	4.7781
.92			.9714+	1.4571+	1.9428	2.4285+	2.9142+	3.3999+	3.8856+	4.3713+	4.8570+
.93			.9873	1.4809+	1.9746	2.4682+	2.9619	3.4555+	3.9491+	4.4428	4.9364+
.94			1.0033	1.5049–	2.0065+	2.5081–	3.0098	3.5114	4.0130+	4.5146+	5.0163–
.95			1.0193	1.5290	2.0386+	2.5483	3.0579+	3.5676	4.0772+	4.5869	5.0965+
.96			1.0354+	1.5532–	2.0709	2.5886+	3.1063+	3.6240+	4.1418	4.6595	5.1772+
.97			1.0517	1.5775+	2.1033+	2.6292–	3.1550–	3.6808+	4.2067	4.7325	5.2583+
.98			1.0680	1.6020	2.1359+	2.6699+	3.2039+	3.7379	4.2719	4.8059	5.3398+
.99			1.0844	1.6265+	2.1687+	2.7109	3.2531–	3.7952+	4.3374+	4.8796	5.4218
1.00			1.1008+	1.6512+	2.2017	2.7521	3.3025+	3.8529	4.4033+	4.9537+	5.5041+
1.01							3.3521+	3.9108+	4.4695–	5.0282+	5.5869+
1.02							3.4020+	3.9691	4.5361	5.1031	5.6701
1.03							3.4522	4.0276	4.6029+	5.1783+	5.7537–
1.04							3.5026–	4.0864–	4.6702+	5.2539–	5.8377–
1.05							3.5532+	4.1454+	4.7376+	5.3299–	5.9221–
1.06							3.6041+	4.2048+	4.8055–	5.4062–	6.0069–
1.07							3.6552+	4.2644+	4.8737–	5.4829–	6.0921–
1.08							3.7066+	4.3244–	4.9421+	5.5599+	6.1777–
1.09							3.7582–	4.3846–	5.0109+	5.6373–	6.2637–
1.10							3.8100+	4.4450+	5.0800+	5.7151–	6.3501–
1.11							3.8621+	4.5058–	5.1495–	5.7932–	6.4369+
1.12							3.9144+	4.5668+	5.2192+	5.8716+	6.5240+
1.13							3.9670–	4.6281+	5.2893–	5.9504+	6.6116–
1.14							4.0197+	4.6897–	5.3596+	6.0296+	6.6996–
1.15							4.0727+	4.7515+	5.4303+	6.1091+	6.7879+
1.16							4.1260–	4.8136+	5.5013+	6.1890–	6.8766+
1.17							4.1794+	4.8760+	5.5726–	6.2692–	6.9657+
1.18							4.2331+	4.9387–	5.6442–	6.3497+	7.0552+
1.19							4.2871–	5.0016–	5.7161–	6.4306+	7.1451+
1.20							4.3412+	5.0648	5.7883–	6.5118+	7.2354–
1.21								5.1282	5.8608	6.5934	7.3260
1.22								5.1919+	5.9336+	6.6753+	7.4170+
1.23								5.2559–	6.0067+	6.7575+	7.5084–
1.24								5.3201	6.0801+	6.8401+	7.6001+
1.25								5.3846–	6.1538+	6.9230+	7.6923–
1.26								5.4493+	6.2278+	7.0063–	7.7848–
1.27								5.5143+	6.3021–	7.0898+	7.8776+
1.28								5.5796	6.3767–	7.1738–	7.9708+
1.29								5.6451–	6.4515+	7.2580–	8.0644+
1.30								5.7109	6.5267+	7.3425+	8.1584–
1.31								5.7769–	6.6022	7.4274+	8.2527–
1.32								5.8432	6.6779–	7.5126+	8.3474–
1.33								5.9097–	6.7539+	7.5982–	8.4424+
1.34								5.9765	6.8302+	7.6840+	8.5378+
1.35								6.0435–	6.9068+	7.7702	8.6336–
1.36								6.1108	6.9837+	7.8567–	8.7297–
1.37								6.1783–	7.0609–	7.9435+	8.8261+
1.38								6.2461	7.1383+	8.0306+	8.9229+
1.39								6.3141–	7.2161	8.1181	9.0201–
1.40								6.3823+	7.2941–	8.2058+	9.1176+
1.41									7.3724	8.2939+	9.2155–
1.42									7.4509+	8.3823+	9.3137–
1.43									7.5298	8.4710+	9.4122+
1.44									7.6089+	8.5600+	9.5111+
1.45									7.6883+	8.6493+	9.6104–
1.46									7.7680–	8.7390–	9.7100–
1.47									7.8479+	8.8289+	9.8099+
1.48									7.9281+	8.9192–	9.9102–
1.49									8.0086+	9.0097+	10.0108–
1.50									[illegible]	[illegible]	[illegible]

TABLE 5.—*Discharge in acre-feet for twenty-four hour periods, of rectangular weirs from 1 to 10 feet long, without end contractions, computed from the formula* $Q=3.33\ LH^{\frac{3}{2}}$—Cont'd.

Depth on weir.	1-foot weir.	1½-foot weir.	2-foot weir.	3-foot weir.	4-foot weir.	5-foot weir.	6-foot weir.	7-foot weir.	8-foot weir.	9-foot weir.	10-foot weir.
Feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1.51									8.1704−	9.1917−	10.2120+
1.52									8.2517−	9.2832−	10.3146+
1.53									8.3333−	9.3749−	10.4166+
1.54									8.4151−	9.4670+	10.5189−
1.55									8.4972−	9.5594−	10.6215+
1.56									8.5796−	9.6520−	10.7245−
1.57									8.6622−	9.7450−	10.8278−
1.58									8.7451−	9.8382+	10.9314−
1.59									8.8282+	9.9316−	11.0353+
1.60									8.9117−	10.0256+	11.1396−
1.61										10.1198−	11.2442−
1.62										10.2142−	11.3491−
1.63										10.3089−	11.4543+
1.64										10.4039+	11.5599+
1.65										10.4992−	11.6658+
1.66										10.5948−	11.7720+
1.67										10.6907−	11.8786−
1.68										10.7869−	11.9854+
1.69										10.8833−	12.0925−
1.70										10.9801−	12.2001−
1.71										11.0771−	12.3079−
1.72										11.1744−	12.4160−
1.73										11.2720−	12.5244+
1.74										11.3699−	12.6332−
1.75										11.4680−	12.7422+
1.76										11.5665−	12.8516+
1.77										11.6652−	12.9613+
1.78										11.7642−	13.0713+
1.79										11.8634+	13.1816+
1.80										11.9630+	13.2922+
1.81											13.4031+
1.82											13.5144−
1.83											13.6259+
1.84											13.7377+
1.85											13.8499−
1.86											13.9623+
1.87											14.0751−
1.88											14.1881+
1.89											14.3015−
1.90											14.4152−
1.91											14.5291+
1.92											14.6434−
1.93											14.7579+
1.94											14.8728−
1.95											14.9879−
1.96											15.1033+
1.97											15.2191−
1.98											15.3351+
1.99											15.4514+
2.00											15.5680+

TABLE 5.—*Discharges, in cubic feet per second for two-hour periods, of rectangular weirs from 1 to 10 feet long, with two end contractions, computed from the formula* $Q=3.33(L-.2H)h^{\frac{3}{2}}$.

Depth of water on crest.	1-foot weir.	1¼-foot weir.	2-foot weir.	3-foot weir.	4-foot weir.	5-foot weir.	6-foot weir.	7-foot weir.	8-foot weir.	9-foot weir.	10-foot weir.
Feet.	Cu. ft. per sec.	Cu. ft. per sec.	Cu. ft. per sec.	Cu. ft. per sec.	Cu. ft. per sec.	Cu. ft. per sec.	Cu. ft. per sec.	Cu. ft. per sec.	Cu. ft. per sec.	Cu. ft. per sec.	Cu. ft. per sec.
0.01	0.0033+	0.0050−	0.0067−	0.0100−	0.0133+	0.0166+	0.0200−	0.0233+	0.0266+	0.0300−	0.0333−
.02	.0094−	.0141−	.0188−	.0282+	.0376+	.0471−	.0565−	.0659−	.0753+	.0847+	.0941+
.03	.0172−	.0259−	.0345+	.0518+	.0691+	.0864+	.1037+	.1210+	.1383+	.1556+	.1729+
.04	.0264+	.0397+	.0531−	.0797+	.1063+	.1330−	.1596+	.1863−	.2129+	.2395+	.2662−
.05	.0369−	.0555−	.0741−	.1113+	.1485+	.1858−	.2230+	.2602+	.2975−	.3347+	.3719+
.06	.0484−	.0728+	.0973−	.1462+	.1952−	.2441+	.2931−	.3420−	.3909+	.4399−	.4888+
.07	.0608+	.0916+	.1225−	.1842−	.2458+	.3075−	.3692−	.4308+	.4925+	.5542−	.6159−
.08	.0741+	.1118+	.1495−	.2248+	.3002−	.3755+	.4509−	.5262+	.6016−	.6769+	.7523−
.09	.0883−	.1332+	.1782+	.2681+	.3580+	.4479+	.5378+	.6278−	.7177−	.8076−	.7975−
.10	.1032−	.1558+	.2085+	.3138+	.4191+	.5244+	.6207+	.7350+	.8403+	.9456+	1.0509+
.11	.1188+	.1796−	.2403+	.3618−	.4833−	.6048−	.7263−	.8477+	.9692+	1.0907+	1.2122+
.12	.1351+	.2043+	.2735+	.4120−	.5504−	.6888+	.8272+	.9657−	1.1041−	1.2425+	1.3809+
.13	.1520+	.2301−	.3081+	.4642−	.6203−	.7764−	.9324+	1.0885+	1.2446+	1.4007+	1.5568−
.14	.1696−	.2568−	.3440−	.5184+	.6929−	.8673−	1.0417+	1.2162−	1.3906+	1.5650+	1.7395−
.15	.1877−	.2844−	.3811+	.5746−	.7680+	.9615−	1.1549+	1.3484−	1.5418+	1.7353−	1.9288−
.16	.2063+	.3129−	.4194+	.6325+	.8457−	1.0588−	1.2719+	1.4850+	1.6981+	1.9113−	2.1244−
.17	.2255−	.3422−	.4589−	.6923−	.9257+	1.1591+	1.3925+	1.6259+	1.8593+	2.0927+	2.3262−
.18	.2451+	.3723+	.4995−	.7538−	1.0081−	1.2624−	1.5167−	1.7710−	2.0253−	2.2796−	2.5339−
.19	.2653+	.4032+	.5411−	.8169−	1.0927−	1.3685−	1.6442+	1.9200+	2.1958+	2.4716+	2.7474−
.20	.2859+	.4349−	.5838−	.8816+	1.1795−	1.4773+	1.7752−	2.0730−	2.3708+	2.6687−	2.9665+
.21	.3070+	.4672+	.6275−	.9479+	1.2684−	1.5888+	1.9093−	2.2298−	2.5502+	2.8707−	3.1911+
.22	.3285+	.5003+	.6721+	1.0157+	1.3594−	1.7030−	2.0466−	2.3902+	2.7338+	3.0775−	3.4211−
.23	.3504+	.5341−	.7177+	1.0850+	1.4524−	1.8197−	2.1870−	2.5543−	2.9216+	3.2889+	3.6562+
.24	.3727+	.5685−	.7643−	1.1558−	1.5473+	1.9388+	2.3304−	2.7219−	3.1134+	3.5049+	3.8965−
.25	.3954+	.6036−	.8117−	1.2279+	1.6442−	2.0604+	2.4767−	2.8929+	3.3092−	3.7254+	4.1417−
.26	.4185+	.6393−	.8600−	1.3015−	1.7429+	2.1844+	2.6259−	3.0674−	3.5088+	3.9503+	4.3918−
.27	.4420−	.6756−	.9091+	1.3763+	1.8435+	2.3107+	2.7779−	3.2451−	3.7123−	4.1794+	4.6466+
.28	.4658−	.7124+	.9591+	1.4525+	1.9459−	2,4393−	2.9326+	3.4260+	3.9194+	4.4128−	4.9062−
.29	.4899−	.7499+	1.0099+	1.5300−	2.0500+	2.5701−	3.0901+	3.6102−	4.1302+	4.6502+	5.1703−
.30	.5143+	.7879+	1.0615+	1.6087−	2.1559−	2.7030+	3.2502+	3.7974−	4.3446−	4.8917+	5.4389+
.31	.5391+	.8265+	1.1139−	1.6886+	2.2634+	2.8382−	3.4129+	3.9877−	4.5624+	5.1372+	5.7120−
.32	.5612+	.8656+	1.1670+	1.7698+	2.3726−	2.9754−	3.5782−	4.1810−	4.7838−	5.3866−	5.9894−
.33	.5896+	.9052+	1.2209−	1.8521+	2.4834+	3.1147−	3.7460−	4.3772+	5.0085−	5.6398−	6.2710+
.34	.6153−	.9454−	1.2755−	1.9356+	2.5958+	3.2560+	3.9162−	4.5764−	5.2366−	5.8967+	6.5569+
.35	.6413−	.9860+	1.3308−	2.0203−	2.7098+	3.3993+	4.0888+	4.7784−	5.4679−	6.1574+	6.8469+
.36	.6675−	1.0271+	1.3868−	2.1061−	2.8253+	3.5446+	4.2639−	4.9832−	5.7025−	6.4217+	7.1410+
.37	.6940−	1.0687+	1.4435−	2.1929+	2.9424−	3.6918+	4.4413−	5.1907+	5.9402−	6.6897−	7.4391+
.38	.7208−	1.1108−	1.5008+	2.2809−	3.0609−	3.8409+	4.6210−	5.4010+	6.1811−	6.9611+	7.7412−
.39	.7478−	1.1533−	1.5588+	2.3699−	3.1809−	3.9919+	4.8030−	5.6140+	6.4250+	7.2361−	8.4471+
.40	.7750+	1.1963−	1.6175−	2.4599−	3.3023+	4.1448−	4.9872−	5.8296+	6.6721−	7.5145−	8.3569+
.41	.8025+	1.2396+	1.6768−	2.5510−	3.4252−	4.2994+	5.1736+	6.0478+	6.9221−	7.7963−	8.6705−
.42	.8303−	1.2835−	1.7367−	2.6431−	3.5494+	4.4558+	5.3622+	6.2686+	7.1750+	8.0814+	8.9878+
.43	.8582+	1.3277−	1.7972−	2.7361+	3.6751−	4.6140+	5.5530+	6.4920−	7.4309+	8.3699−	9.3088+
.44	.8864−	1.3723+	1.8583−	2.8302−	3.8021−	4.7740−	5.7459−	6.7178−	7.6897+	8.6616+	9.6335+
.45	.9148−	1.4174−	1.9200−	2.9252+	3.9304+	4.9357−	5.9409−	6.9461+	7.9513+	8.9565+	9.9618−
.46	.9433+	1.4628−	1.9823−	3.0212−	4.0601−	5.0990+	6.1379+	7.1768+	8.2158−	9.2547−	10.2936−
.47	.9721+	1.5086+	2.0451−	3.1181−	4.1911−	5.2640+	6.3370+	7.4100−	8.4830−	9.5559+	10.6289+
.48	1.0011−	1.5548−	2.1085−	3.2159+	4.3233+	5.4307+	6.5381+	7.6455+	8.7529+	9.8603+	10.9677+
.49	1.0303−	1.6014−	2.1724+	3.3146+	4.4568+	5.5990+	6.7412+	7.8834−	9.0256−	10.1678−	11.3100−
.50	1.0596−	1.6483−	2.2369+	3.4143−	4.5916−	5.7689+	6.9463−	8.1236−	9.3009+	10.4783−	11.6556−
.51	....	1.6955+	2.301 +	3.5148−	4.7276+	5.9404+	7.1533−	8.3661−	9.5789+	10.7918−	12.0046−
.52	....	1.7431+	2.3675−	3.6162−	4.8648+	6.1135+	7.3622−	8.6109−	9.8595+	11.1082+	12.3569−
.53	....	1.7911+	2.4335+	3.7184+	5.0033−	6.2881+	7.5730+	8.8579−	10.1427+	11.4276+	12.7125−
.54	....	1.8394−	2.5001−	3.8215−	5.1429−	6.4643−	7.7857−	9.1071+	10.4285+	11.7499+	13.0713+
.55	....	1.8880+	2.5671+	3.9254+	5.2837−	6.6420−	8.0003−	9.3585+	10.7168+	12.0751−	13.4334−
.56	....	1.9369+	2.6347−	4.0302−	5.4257−	6.8211+	8.2166+	9.6121+	11.0076+	12.4031+	13.7986−
.57	....	2 9862−	2.7027+	4.1357+	5.5688−	7.0018+	8.4348+	9.8679−	11.3009+	12.7339+	14.1670−
.58	....	2.0357+	2.7712−	4.2421+	5.7130+	7.1839+	8.6548+	10.1257+	11.5967−	13.0676−	14.5385−
.59	....	2.0856−	2.8402−	4.3493−	5.8584−	7.3675−	8.8766+	10.3857+	11.8948+	13.4040−	14.9131−
.60	....	2.1357+	2.9096−	4.4572+	6.0049−	7.5525+	9.1001+	10.6478−	12.1954+	13.7431−	15.2907+
.61	....	2.1862−	2.9794+	4.5659+	6.1524+	7.7389+	9.3254+	10.9119+	12.4984+	14.0849+	15.6714+
.62	....	2.2369+	3.0198−	4.6754+	6.3011−	7.9268−	9.5524+	11.1781−	12.8038−	14.4294+	16.0551−
.63	....	2.2879+	3.1205+	4.7857−	6.4508+	8.1160−	9.7811+	11.4463−	13.1114+	14.7766−	16.4418−
.64	....	2.3392+	3.1917−	4.8966+	6.6016+	8.3066−	10.0115+	11.7165−	13.4214+	15.1264+	16.8314−
.65	....	2.3908−	3.2633−	5.0084−	6.7534+	8.4985+	10.2436−	11.9887−	13.7337+	15.4788+	17.2239−
.66	....	2.4426−	3.3353+	5.1208+	6.9063+	8.6918+	10.4773+	12.2628+	14.0483+	15.8338+	17.6193+
.67	....	2.4946+	3.4078−	5.2340−	7.0602+	8.8865−	10.7127−	12.5389+	14.3652−	16.1914−	18.0176+
.68	....	2.5470−	3.4806−	5.3479−	7.2151+	9.0824+	10.9497−	12.8170−	14.6842+	16.5515−	18.4188−
.69	....	2.5995+	3.5538+	5.4625−	7.3711−	9.2797−	11.1883−	13.0969+	15.0055+	16.9141+	18.8227+
.70	....	2.6523+	3.6275−	5.5777+	7.5280−	9.4782+	11.4285−	13.3787+	15.3290+	17.2793−	19.2295+
.71	....	2.7054+	3.7015−	5.6937−	7.6859−	9.6781−	11.6703−	13.6625−	15.6547−	17.6469−	19.6391−
.72	....	2.7587−	3.7759+	5.8103+	7.8448−	9.8792−	11.9136+	13.9481−	15.9825−	18.0169+	20.0514−

TABLE 5.—*Discharges, in cubic feet per second for two-hour periods, of rectangular weirs from 1 to 10 feet long, with two end contractions, computed from the formula* $Q=3.33\,(L-.2H)\,h^{\frac{3}{2}}$—Continued.

Depth of water on crest.	1-foot weir.	1½-foot weir.	2-foot weir.	3-foot weir.	4-foot weir.	5-foot weir.	6-foot weir.	7-foot weir.	8-foot weir.	9-foot weir.	10-foot weir.
Feet.	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*
0.73	....	2.8122 -	3.8507	5.9276 +	8.0046 +	10.0816	12.1585 +	14.2355 -	16.3125 −	18.3894 +	20.4664 −
.74	....	2.8659 +	3.9258 +	6.0456 +	8.1654 +	10.2852	12.4050 -	14.5248 −	16.6446 −	18.7643 +	20.8841 +
.75	....	2.9199 +	4.0014	6.1643	8.3272	10.4901	12.6530 −	14.8159 −	16.9788 −	19.1417 −	21.3045 +
.76	....	....	4.0772 +	6.2835 +	8.4898 +	10.6961 +	12.9024 −	15.1087 +	17.3150 +	19.5213 +	21.7276 +
.77	....	....	4.1535	6.4035	8.6535 −	10.9034 -	13.1534 +	15.4034 +	17.6534 +	19.9034 −	22.1534 −
.78	....	....	4.2301	6.5240 +	8.8180 −	11.1119 -	13.4059 +	15.6999 −	17.9938 +	20.2878 −	22.5818 −
.79	....	....	4.3070	6.6452 +	8.9834 +	11.3216 -	13.6599 −	15.9981 -	18.3363 +	20.6745 +	23.0127 +
.80	....	....	4.3843	6.7670 +	9.1498 −	11.5325 -	13.9153 -	16.2980 +	18.6808 −	21.0635 +	23.4463 −
.81	....	....	4.4619	6.8894 +	9.3170 +	11.7446	14.1722	16.5997 +	19.0273 −	21.4549 −	23.8824 +
.82	....	....	4.5398 +	7.0125	9.4851 +	11.9578 -	14.4305	16.9031 +	19.3758 −	21.8485 −	24.3211 +
.83	....	....	4.6181	7.1361 +	9.6541 +	12.1722	14.6902 +	17.2082 +	19.7263 −	22.2443 +	24.7623 +
.84	....	....	4.6967	7.2603 +	9.8240 +	12.3877	14.9514	17.5150 +	20.0787 +	22.6424 -	25.2061 −
.85	....	....	4.7756	7.3851 +	9.9947 +	12.6043 +	15.2139 -	17.8235 +	20.4331 +	23.0427 −	25.6523 −
.86	....	....	4.8548	7.5105 +	10.1663 -	12.8221 +	15.4779	18.1337 −	20.7894 +	23.4452 +	26.1010 −
.87	....	....	4.9343	7.6365 +	10.3388	13.0410	15.7432 -	18.4455 −	21.1477 −	23.8499 +	26.5522 −
.88	....	....	5.0141 +	7.7631	10.5120 -	13.2610	16.0099 +	18.7589 −	21.5079 −	24.2568 +	27.0058 −
.89	....	....	5.0942 +	7.8902	10.6861 +	13.4821	16.2780 +	19.0740 −	21.8699 -	24.6659 -	27.4618 +
.90	....	....	5.1746 +	8.0178 +	10.8610 -	13.7042 +	16.5474 +	19.3907	22.2339 −	25.0771 −	27.9203 −
.91	....	....	5.2553 +	8.1461	11.0368	13.9275	16.8182 +	19.7089 +	22.5997 −	25.4904 -	28.3811 +
.92	....	....	5.3363 +	8.2748 +	11.2133 -	14.1518 -	17.0903 +	20.0288 +	22.9673 +	25.9058 +	28.8443 +
.93	....	....	5.4176	8.4011 +	11.3907	14.3772 +	17.3638	20.3503	23.3368 +	26.3234 -	29.3099 +
.94	....	....	5.4991 +	8.5340	11.5688 +	14.6037	17.6385	20.6733 +	23.7082 −	26.7430 +	29.7779 −
.95	....	....	5.5810	8.6643 -	11.7477 +	14.8311 +	17.9145 -	20.9979 +	24.0813 +	27.1647 +	30.2481 +
.96	....	....	5.6630 +	8.7953 −	11.9275	15.0597	18.1919 -	21.3241 −	24.4563 +	27.5885 +	30.7207 +
.97	....	....	5.7454 -	8.9267	12.1080	15.2892 +	18.4705 +	21.6518 −	24.8331 −	28.0143 +	31.1956 +
.98	....	....	5.8280 +	9.0586 +	12.2892 -	15.5198 +	18.7504 +	21.9810 +	25.2116 +	28.4422 +	31.6728 +
.99	....	....	5.9109	9.1911	12.4712 +	15.7514 +	19.0316 −	22.3118 −	25.5919 +	28.8721 +	32.1523 −
1.00	....	....	5.9940	9.3240	12.6540	15.9840	19.3140	22.6440	25.9740	29.3040	32.6340
1.01	....	....	....	....	....	....	19.5977	22.9777 +	26.3578 +	29.7379 -	33.1180 −
1.02	....	....	....	....	....	....	19.8826	23.3130 −	26.7434 −	30.1738 -	33.6042 −
1.03	....	....	....	....	....	....	20.1687 -	23.6497	27.1307 −	30.6116 +	34.0926 +
1.04	....	....	....	....	....	....	20.4561	23.9879 -	27.5197 −	31.0515 -	34.5832 +
1.05	....	....	....	....	....	....	20.7447	24.3275 +	27.9104 −	31.4932 +	35.0761 −
1.06	....	....	....	....	....	....	21.0345	24.6686 +	28.3028 −	31.9369 +	35.5711 −
1.07	....	....	....	....	....	....	21.3255	25.0112	28.6969 −	32.3826 −	36.0683 −
1.08	....	....	....	....	....	....	21.6176 +	25.3551 +	29.0926 +	32.8301 −	36.5676 −
1.09	....	....	....	....	....	....	21.9110	25.7005 +	29.4900 +	33.2795 +	37.0691 −
1.10	....	....	....	....	....	....	22.2055 +	26.0473 +	29.8891 +	33.7309 −	37.5727 −
1.11	....	....	....	....	....	....	22.5012 -	26.3955 +	30.2898 +	34.1841 +	38.0784 +
1.12	....	....	....	....	....	....	22.7981	26.7451 +	30.6922 −	34.6392 +	38.5862 +
1.13	....	....	....	....	....	....	23.0961 -	27.0961 +	31.0961 +	35.0962 −	39.0962 −
1.14	....	....	....	....	....	....	23.3953	27.4485	31.5017 +	35.5550 −	39.6082 −
1.15	....	....	....	....	....	....	23.6956	27.8022 +	31.9089 +	36.0156 −	40.1223 −
1.16	....	....	....	....	....	....	23.9970	28.1573 +	32.3177 −	36.4781 −	40.6384 +
1.17	....	....	....	....	....	....	24.2995 +	28.5138 −	32.7281 −	36.9423 +	41.1566 +
1.18	....	....	....	....	....	....	24.6032	28.8716 -	33.1400 +	37.4084 +	41.6769 −
1.19	....	....	....	....	....	....	24.9079 +	29.2307 -	33.5535 +	37.8763 +	42.1991 +
1.20	....	....	....	....	....	....	25.2138 +	29.5912 −	33.9686 +	38.3460 +	42.7234 +
1.21	....	....	....	....	....	....	....	29.9530 -	34.3852 +	38.8175 −	43.2497 +
1.22	....	....	....	....	....	....	....	30.3161 -	34.8034 +	39.2907 −	43.7780 −
1.23	....	....	....	....	....	....	....	30.6805 -	35.2231 +	39.7657 −	44.3083 −
1.24	....	....	....	....	....	....	....	31.0463	35.6443 +	40.2424 +	44.8405 +
1.25	....	....	....	....	....	....	....	31.4133	36.0671 -	40.7209 −	45.3747 +
1.26	....	....	....	....	....	....	....	31.7816	36.4913 +	41.2011 +	45.9109 −
1.27	....	....	....	....	....	....	....	32.1511 +	36.9171	41.6830 +	46.4490 −
1.28	....	....	....	....	....	....	....	32.5220 -	37.3443 +	42.1667 −	46.9890 +
1.29	....	....	....	....	....	....	....	32.8941 -	37.7730 +	42.6520 +	47.5310 −
1.30	....	....	....	....	....	....	....	33.2674 -	38.2032 +	43.1391 −	48.0749 −
1.31	....	....	....	....	....	....	....	33.6420 -	38.6349 +	43.6278 −	48.6207 −
1.32	....	....	....	....	....	....	....	34.0179 −	39.0680 +	44.1182 −	49.1684 −
1.33	....	....	....	....	....	....	....	34.3950	39.5026 +	44.6103 −	49.7179 +
1.34	....	....	....	....	....	....	....	34.7733 −	39.9386 +	45.1040 +	50.2694 −
1.35	....	....	....	....	....	....	....	35.1528 +	40.3761 +	45.5994 +	50.8227 −
1.36	....	....	....	....	....	....	....	35.5335 -	40.8150 −	46.0964 +	51.3779 −
1.37	....	....	....	....	....	....	....	35.9155 +	41.2553 +	46.5951 +	51.9349 +
1.38	....	....	....	....	....	....	....	36.2987	41.6970 +	47.0954 +	52.4938 −
1.39	....	....	....	....	....	....	....	36.6830 +	42.1402	47.5973 +	53.0545 −
1.40	....	....	....	....	....	....	....	37.0685 -	42.5847 −	48.1009 −	53.6170 +
1.41	....	....	....	....	....	....	....	....	43.0306 +	48.6060 −	54.1813 +
1.42	....	....	....	....	....	....	....	....	43.4779 +	49.1127 +	54.7475 −
1.43	....	....	....	....	....	....	....	....	43.9266 -	49.6210 +	55.3154 +
1.44	....	....	....	....	....	....	....	....	44.3767 −	50.1309 +	55.8852 −
1.45	....	....	....	....	....	....	....	....	44.8281 +	50.6424 +	[illegible] −

TABLE 5.—*Discharges, in cubic feet per second for two-hour periods, of rectangular weirs from 1 to 10 feet long, with two end contractions, computed from the formula* $Q=3.33 (L.-.2H) h^{\frac{3}{2}}$—Continued.

Depth of water on crest.	1-foot weir.	1½-foot weir.	2-foot weir.	3-foot weir.	4-foot weir.	5-foot weir.	6-foot weir.	7-foot weir.	8-foot weir.	9-foot weir.	10-foot weir.
Feet.	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*
1.46									45.2809+	51.1555−	57.0300−
1.47									45.7351−	51.6701−	57.6050+
1.48									46.1905+	52.1862+	58.1819−
1.49									46.6474−	52.7039−	58.7604+
1.50									47.1055+	53.2231+	59.3407+
1.51									47.5650+	53.7439−	59.9228−
1.52									48.0258+	54.2662−	60.5065+
1.53									48.4879+	54.7900−	61.0920+
1.54									48.9513+	55.3153−	61.6792−
1.55									49.4161−	55.8421−	62.2681−
1.56									49.8821−	56.3704−	62.8587−
1.57									50.3494−	56.9002−	63.4510−
1.58									50.8180−	57.4314+	64.0449+
1.59									51.2878+	57.9642−	64.6405+
1.60									51.7569+	58.4984−	65.2378+
1.61										59.0341−	65.8368−
1.62										59.5712−	66.4374−
1.63										60.1098−	67.0396+
1.64										60.6498−	67.6435+
1.65										61.1912+	68.2491−
1.66										61.7341+	68.8562−
1.67										62.2784+	69.4650−
1.68										62.8241+	70.0753+
1.69										63.3713−	70.6873−
1.70										63.9198+	71.3009−
1.71										64.4697+	71.9160+
1.72										65.0211−	72.5328−
1.73										65.5738−	73.1511−
1.74										66.1279−	73.7710−
1.75										66.6834−	74.3924+
1.76										67.2402−	75.0154+
1.77										67.7984−	75.6400−
1.78										68.3579+	76.2661−
1.79										68.9189−	76.8937+
1.80										69.4811+	77.5229+
1.81											78.1536+
1.82											78.7858+
1.83											79.4196−
1.84											80.0548+
1.85											80.6916−
1.86											81.3298+
1.87											81.9695+
1.88											82.6108−
1.89											83.2535−
1.90											83.8976+
1.91											84.5433−
1.92											85.1904−
1.93											85.8389+
1.94											86.4889+
1.95											87.1404−
1.96											87.7933−
1.97											88.4476+
1.98											89.1034−
1.99											89.7606−
2.00											90.4192−

TABLE 6.—*Discharges, in acre-feet for two-hour periods, of rectangular weirs from 1 to 10 feet long, with two end contractions, computed from the formula* $Q=3.33\,(L-.2H)\,H^{\frac{3}{2}}$.

Depth of water on crest	1-foot weir.	1½-foot weir.	2-foot weir.	3-foot weir.	4-foot weir.	5-foot weir.	6-foot weir.	7-foot weir.	8-foot weir.	9-foot weir.	10-foot weir.
Feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
0.01	0.00055	0.0008	0.0011	0.0017	0.0022	0.0028	0.0033	0.0039	0.0044	0.0050 -	0.0055 -
.02	.00155	.0023	.0031	.0047	.0062	.0078	.0093	.0109	.0125	.0140 +	.0156
.03	.0028	.0043	.0057	.0086	.0114	.0143	.0171	.0200	.0229	.0257 +	.0286 –
.04	.0044	.0066	.0088	.0132	.0176	.0220	.0264	.0308	.0352	.0396 –	.0440 –
.05	.0061	.0092	.0122	.0184	.0246	.0307	.0369	.0430	.0492	.0553 +	.0615 -
.06	.0080	.0120	.0161	.0242	.0323	.0403	.0484	.0565	.0646	.0727 +	.0808 -
.07	.0101	.0151	.0202	.0304	.0406	.0508	.0610	.0712	.0814	.0916 +	.1018 -
.08	.0123	.0185	.0247	.0372	.0496	.0621	.0745	.0870	.0994	.1119 –	.1243 +
.09	.0146	.0220	.0295	.0443	.0592	.0740	.0889	.1038	.1186	.1335 –	.1483 +
.10	.0171	.0258	.0345	.0519	.0693	.0867	.1041	.1215	.1389	.1563 +	.1737 +
.11	.0196	.0297	.0397	.0598	.0799	.1000	.1200	.1401	.1602	.1803 -	.2004
.12	.0223	.0338	.0452	.0681	.0910	.1139	.1367	.1596	.1825	.2054 -	.2283
.13	.0251	.0380	.0509	.0767	.1025	.1283	.1541	.1799	.2057	.2315 +	.2573 +
.14	.0280	.0424	.0569	.0857	.1145	.1434	.1722	.2010	.2299	.2587	.2875 +
.15	.0310	.0470	.0630	.0950	.1269	.1589	.1909	.2229	.2548	.2868 +	.3188 +
.16	.0341	.0517	.0693	.1046	.1398	.1750	.2102	.2455	.2807	.3159 +	.3511 +
.17	.0373	.0566	.0758	.1144	.1530	.1916	.2302	.2687	.3073	.3459 +	.3845
.18	.0405	.0615	.0826	.1246	.1666	.2087	.2507	.2927	.3348	.3768 -	.4188 +
.19	.0439	.0666	.0894	.1350	.1806	.2262	.2718	.3174	.3629	.4085 +	.4541 +
.20	.0473	.0719	.0965	.1457	.1950	.2442	.2934	.3426	.3919	.4411 +	.4903 +
.21	.0507	.0772	.1037	.1567	.2096	.2626	.3156	.3686	.4215	.4745 –	.5275 -
.22	.0543	.0827	.1111	.1679	.2247	.2815	.3383	.3951	.4519	.5087 -	.5655 –
.23	.0579	.0883	.1186	.1793	.2401	.3008	.3615	.4222	.4829	.5436 +	.6043 +
.24	.0616	.0940	.1263	.1910	.2558	.3205	.3852	.4499	.5146	.5793 +	.6440 +
.25	.0654	.0998	.1342	.2030	.2718	.3406	.4094	.4782	.5470	.6158	.6846 -
.26	.0692	.1057	.1421	.2151	.2881	.3611	.4340	.5070	.5800	.6529 +	.7259 +
.27	.0731	.1117	.1503	.2275	.3047	.3819	.4592	.5364	.6136	.6908 +	.7680 +
.28	.0770	.1178	.1585	.2401	.3216	.4032	.4847	.5663	.6478	.7294 -	.8109 +
.29	.0810	.1240	.1669	.2529	.3388	.4248	.5108	.5967	.6827	.7686 +	.8546 –
.30	.0850	.1302	.1755	.2659	.3563	.4468	.5372	.6277	.7181	.8086 –	.8990 -
.31	.0891	.1366	.1841	.2791	.3741	.4691	.5641	.6591	.7541	.8491 +	.9441 +
.32	.0933	.1431	.1929	.2925	.3922	.4918	.5914	.6911	.7907	.8903 +	.9900 -
.33	.0975	.1496	.2018	.3061	.4105	.5148	.6192	.7235	.8279	.9322 -	1.0365 +
.34	.1017	.1563	.2108	.3199	.4291	.5382	.6473	.7564	.8655	.9747 –	1.0838 –
.35	.1060	.1630	.2200	.3339	.4479	.5619	.6758	.7898	.9038	1.0178	1.1317 +
.36	.1103	.1698	.2292	.3481	.4670	.5859	.7048	.8237	.9426	1.0614 +	1.1803 +
.37	.1147	.1766	.2386	.3625	.4863	.6102	.7341	.8580	.9819	1.1057 -	1.2296 +
.38	.1191	.1836	.2481	.3770	.5059	.6349	.7638	.8927	1.0217	1.1506	1.2795 +
.39	.1236	.1906	.2577	.3917	.5258	.6598	.7939	.9279	1.0620	1.1960 +	1.3301 +
.40	.1281	.1977	.2673	.4066	.5458	.6851	.8243	.9636	1.1028	1.2421	1.3813 +
.41	.1327	.2049	.2771	.4216	.5661	.7106	.8551	.9996	1.1441	1.2886 +	1.4331 +
.42	.1372	.2121	.2871	.4369	.5867	.7365	.8863	1.0361	1.1860	1.3358	1.4856
.43	.1419	.2195	.2971	.4523	.6075	.7627	.9179	1.0731	1.2283	1.3835	1.5387
.44	.1465	.2268	.3072	.4678	.6284	.7891	.9497	1.1104	1.2710	1.4317 -	1.5923 +
.45	.1512	.2343	.3174	.4835	.6497	.8158	.9820	1.1481	1.3143	1.4804 +	1.6466 –
.46	.1559	.2418	.3276	.4994	.6711	.8428	1.0145	1.1863	1.3580	1.5297 –	1.7014 +
.47	.1607	.2494	.3380	.5154	.6927	.8701	1.0474	1.2248	1.4021	1.5795 -	1.7568 +
.48	.1655	.2570	.3485	.5316	.7146	.8976	1.0807	1.2637	1.4468	1.6298 +	1.8128 +
.49	.1703	.2647	.3591	.5479	.7367	.9255	1.1142	1.3030	1.4918	1.6806 +	1.8694 +
.50	.1751	.2724	.3697	.5643	.7589	.9535	1.1481	1.3427	1.5373	1.7319 +	1.9265 +
.51	....	.2803	.3805	.5810	.7814	.9819	1.1824	1.3828	1.5833	1.7838	1.9842 +
.52	....	.2881	.3913	.5977	.8041	1.0105	1.2169	1.4233	1.6297	1.8361 –	2.0425 –
.53	....	.2961	.4022	.6146	.8270	1.0394	1.2517	1.4641	1.6765	1.8889 -	2.1012 +
.54	....	.3040	.4132	.6317	.8501	1.0685	1.2869	1.5053	1.7237	1.9421 +	2.1605 +
.55	....	.3121	.4243	.6488	.8733	1.0978	1.3224	1.5469	1.7714	1.9959	2.2204 –
.56	....	.3202	.4355	.6661	.8968	1.1275	1.3581	1.5888	1.8194	2.0501 -	2.2808 –
.57	....	.3283	.4467	.6836	.9205	1.1573	1.3942	1.6311	1.8679	2.1048	2.3416 +
.58	....	.3365	.4580	.7012	.9443	1.1874	1.4306	1.6737	1.9168	2.1599	2.4031 -
.59	....	.3447	.4694	.7189	.9683	1.2178	1.4672	1.7166	1.9661	2.2155 -	2.4650 –
.60	....	.3530	.4809	.7367	.9925	1.2483	1.5042	1.7600	2.0158	2.2716	2.5274 -
.61	....	.3614	.4925	.7547	1.0169	1.2792	1.5414	1.8036	2.0659	2.3281	2.5903 +
.62	....	.3697	.5041	.7728	1.0415	1.3102	1.5789	1.8476	2.1163	2.3850 +	2.6537 +
.63	....	.3782	.5158	.7910	1.0663	1.3415	1.6167	1.8919	2.1672	2.4424	2.7176 +
.64	....	.3866	.5276	.8094	1.0912	1.3730	1.6548	1.9366	2.2184	2.5002 +	2.7820 +
.65	....	.3952	.5394	.8278	1.1163	1.4047	1.6932	1.9816	2.2700	2.5585 -	2.8469 +
.66	....	.4037	.5513	.8464	1.1415	1.4367	1.7318	2.0269	2.3220	2.6172	2.9123 -
.67	....	.4123	.5633	.8651	1.1670	1.4688	1.7707	2.0725	2.3744	2.6763	2.9781 +
.68	....	.4210	.5753	.8839	1.1926	1.5012	1.8099	2.1185	2.4271	2.7358	3.0444 +
.69	....	.4297	.5874	.9029	1.2184	1.5338	1.8493	2.1648	2.4803	2.7957 +	3.1112 –
.70	....	.4384	.5996	.9219	1.2443	1.5667	1.8890	2.2114	2.5337	2.8561	3.1784 +
.71	....	.4472	.6118	.9411	1.2704	1.5997	1.9290	2.2583	2.5875	2.9168 +	3.2461 +
.72	....	.4560	.6241	.9604	1.2967	1.6329	1.9692	2.3055	2.6417	2.9780 -	3.3143 -
.73	....	.4648	.6365	.9798	1.3231	1.6664	2.0097	2.3530	2.6963	3.0396	3.3829
.74	....	.4737	.6489	.9993	1.3497	1.7000	2.0504	2.4008	2.7512	3.1015 +	3.4519 +
.75	....	.4826	.6614 –	1.0189 –	1.3764 –	1.7339	2.0914	2.4489	2.8064	3.1639 +	3.5214 +

TABLE 6.—*Discharges, in acre-feet for two-hour periods, of rectangular weirs from 1 to 10 feet long, with two end contractions, computed from the formula* $Q=3.33\ (L-.2H)\ H^{\frac{3}{2}}$—Continued.

Depth of water on crest.	1-foot weir.	1¼-foot weir.	2-foot weir.	3-foot weir.	4-foot weir.	5-foot weir.	6-foot weir.	7-foot weir.	8-foot weir.	9-foot weir.	10-foot weir.
Feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
0.76			0.6739+	1.0386+	1.4033−	1.7680−	2.1326+	2.4973+	2.8620−	3.2267+	3.5913+
.77			.6865+	1.0584+	1.4303+	1.8022+	2.1741+	2.5460+	2.9179+	3.2896+	3.6617+
.78			.6992−	1.0784−	1.4575+	1.8367−	2.2159−	2.5950+	2.9742−	3.3534−	3.7325+
.79			.7119+	1.0984−	1.4849−	1.8713+	2.2578+	2.6443+	3.0308−	3.4173−	3.8038−
.80			.7247−	1.1185+	1.5124−	1.9062+	2.3000+	2.6939−	3.0877+	3.4816−	3.8754+
.81			.7375−	1.1388−	1.5400+	1.9413−	2.3425+	2.7438−	3.1450+	3.5463−	3.9475+
.82			.7504−	1.1591−	1.5678−	1.9765−	2.3852−	2.7939+	3.2026+	3.6113+	4.0200+
.83			.7633+	1.1795+	1.5957+	2.0119+	2.4281+	2.8443+	3.2605+	3.6767+	4.0929+
.84			.7763+	1.2001−	1.6238+	2.0476−	2.4713−	2.8950+	3.3188−	3.7425+	4.1663−
.85			.7893+	1.2207−	1.6520+	2.0834−	2.5147−	2.9460+	3.3774−	3.8087+	4.2400+
.86			.8024+	1.2414+	1.6804−	2.1194−	2.5583+	2.9973−	3.4363−	3.8752+	4.3142+
.87			.8156−	1.2622+	1.7089−	2.1555+	2.6022−	3.0488+	3.4955−	3.9421+	4.3888−
.88			.8288−	1.2832−	1.7375+	2.1919−	2.6463−	3.1006+	3.5550+	4.0094−	4.4638−
.89			.8420+	1.3042−	1.7663+	2.2284+	2.6906−	3.1527+	3.6149−	4.0770+	4.5391+
.90			.8553+	1.3253−	1.7952+	2.2652−	2.7351+	3.2051−	3.6750+	4.1450−	4.6149+
.91			.8687−	1.3465−	1.8243−	2.3021−	2.7799−	3.2577−	3.7355−	4.2133+	4.6911+
.92			.8820+	1.3677+	1.8534+	2.3391+	2.8248+	3.3106−	3.7963−	4.2820−	4.7677−
.93			.8955−	1.3891+	1.8828−	2.3764−	2.8700+	3.3637−	3.8573+	4.3510−	4.8446+
.94			.9089+	1.4106−	1.9122+	2.4138+	2.9155−	3.4171−	3.9187+	4.4203−	4.9220−
.95			.9225−	1.4321+	1.9418−	2.4514+	2.9611−	3.4707+	3.9804−	4.4900+	4.9997
.96			.9360+	1.4538−	1.9715−	2.4892+	3.0069+	3.5246+	4.0424−	4.5601−	5.0778+
.97			.9497−	1.4755−	2.0013+	2.5271+	3.0530−	3.6788+	4.1946+	4.6305−	5.1563+
.98			.9633+	1.4973−	2.0313−	2.5653−	3.0992+	3.6332+	4.1672+	4.7012−	5.2352−
.99			.9770+	1.5192−	2.0614−	2.6035+	3.1457+	3.6879−	1.2301−	4.7722+	5.3144+
1.00			.9907+	1.5412−	2.0916−	2.6420−	3.1924−	3.7428+	4.2932+	4.8436+	5.3940+
1.01							3.2393−	3.7980−	4.3567−	4.9154−	5.4740+
1.02							3.2864−	3.8534−	4.4204−	4.9874+	5.5544+
1.03							3.3337−	3.9090+	4.4844+	5.0598−	5.6351+
1.04							3.3812−	3.9649+	4.5487+	5.1325−	5.7162+
1.05							3.4289−	4.0211−	4.6133−	5.2055−	5.7977−
1.06							3.4768−	4.0775−	4.6781+	5.2788+	5.8795+
1.07							3.5249−	4.1341−	4.7433−	5.3525−	5.9617−
1.08							3.5732−	4.1909+	4.8087−	5.4265−	6.0442+
1.09							3.6217−	4.2480+	4.8744−	5.5008−	6.1271+
1.10							3.6703+	4.3053+	4.9403+	5.5754−	6.2104−
1.11							3.7192+	4.3629−	5.0066−	5.6503−	6.2940−
1.12							3.7683−	4.4207−	5.0731−	5.7255−	6.3779−
1.13							3.8175+	4.4787−	5.1399−	5.8010+	6.4622−
1.14							3.8670−	4.5369+	5.2069−	5.8769−	6.5468+
1.15							3.9167+	4.5954+	5.2742+	5.9530−	6.6318−
1.16							3.9664+	4.6541+	5.3418−	6.0294+	6.7171−
1.17							4.0164+	4.7130+	5.4096−	6.1062−	6.8027+
1.18							4.0666+	4.7722−	5.4777−	6.1832+	6.8887+
1.19							4.1170+	4.8315+	5.5460+	6.2606−	6.9751−
1.20							4.1676−	4.8911+	5.6146+	6.3382−	7.0617+
1.21								4.9509+	5.6835+	6.4161+	7.1487+
1.22								5.0109+	5.7526+	6.4943+	7.2360+
1.23								5.0712−	5.8220+	6.5728+	7.3237−
1.24								5.1316+	5.8916+	6.6516+	7.4117−
1.25								5.1923−	5.9615+	6.7307+	7.5000−
1.26								5.2531+	6.0316+	6.8101−	7.5886−
1.27								5.3142+	6.1020−	6.8898−	7.6775+
1.28								5.3755+	6.1726+	6.9697−	7.7668−
1.29								5.4370+	6.2435−	7.0499+	7.8564−
1.30								5.4987+	6.3146−	7.1304+	7.9463−
1.31								5.5607−	6.3859+	7.2112+	8.0365−
1.32								5.6228−	6.4575+	7.2923−	8.1270+
1.33								5.6851+	6.5294−	7.3736−	8.2178+
1.34								5.7476+	6.6014+	7.4552+	8.3090−
1.35								5.8104−	6.6737+	7.5371−	8.4004+
1.36								5.8733+	6.7463−	7.6192+	8.4922+
1.37								5.9364+	6.8191−	7.7017−	8.5843−
1.38								5.9998−	6.8921−	7.7844−	8.6767−
1.39								6.0633+	6.9653+	7.8673+	8.7693+
1.40								6.1270+	7.0388−	7.9506−	8.8623+
1.41									7.1125+	8.0340+	8.9556−
1.42									7.1864+	8.1178+	9.0492−
1.43									7.2606+	8.2018+	9.1430+
1.44									7.3350−	8.2861+	9.2372+
1.45									7.4096+	8.3706+	9.3317−
1.46									7.4844+	8.4554+	9.4264+
1.47									7.5595+	8.5405+	9.5215−
1.48									7.6348+	8.6258+	9.6168+

TABLE 6.—*Discharges, in acre-feet for twenty-four-hour periods, of rectangular weirs from 1 to 10 feet long, with two end contractions, computed from the formula $Q=3.33\ (L-.2H)\ H^{\frac{3}{2}}$*—Continued.

Depth of water on crest.	1-foot weir.	1½-foot weir.	2-foot weir.	3-foot weir.	4-foot weir.	5-foot weir.	6-foot weir.	7-foot weir.	8-foot weir.	9-foot weir.	10-foot weir.
Feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1.49									7.7103 −	8.7114 −	9.7125 −
1.50									7.7870 −	8.7972 −	9.8084 −
1.51									7.8630 −	8.8833 −	9.9046 −
1.52									7.9381 −	8.9696 −	10.0011 −
1.53									8.0145 −	9.0562 −	10.0979 −
1.54									8.0911 −	9.1430 +	10.1949 −
1.55									8.1679 −	9.2301 −	10.2922 +
1.56									8.2450 −	9.3174 +	10.3899 −
1.57									8.3222 −	9.4050 −	10.4878 −
1.58									8.3997 −	9.4928 −	10.5859 +
1.59									8.4773 −	9.5809 −	10.6844 −
1.60									8.5552 −	9.6692 −	10.7831 +
1.61										9.7577 −	10.8821 +
1.62										9.8465 −	10.9814 −
1.63										9.9355 −	11.0809 +
1.64										10.0248 −	11.1807 +
1.65										10.1143 −	11.2808 +
1.66										10.2040 −	11.3812 −
1.67										10.2940 −	11.4818 −
1.68										10.3842 −	11.5827 −
1.69										10.4746 −	11.6838 +
1.70										10.5653 −	11.7853 −
1.71										10.6562 −	11.8869 +
1.72										10.7473 −	11.9889 −
1.73										10.8386 +	12.0911 −
1.74										10.9302 +	12.1935 +
1.75										11.0220 +	12.2963 −
1.76										11.1141 −	12.3992 +
1.77										11.2063 +	12.5025 −
1.78										11.2988 +	12.6060 −
1.79										11.3915 +	12.7097 +
1.80										11.4845 −	12.8137 +
1.81											12.9180 −
1.82											13.0225 −
1.83											13.1272 +
1.84											13.2322 +
1.85											13.3374 +
1.86											13.4429 +
1.87											13.5487 −
1.88											13.6547 −
1.89											13.7609 +
1.90											13.8674 −
1.91											13.9741 −
1.92											14.0811 −
1.93											14.1883 −
1.94											14.2957 −
1.95											14.4034 −
1.96											14.5113 −
1.97											14.6194 +
1.98											14.7278 +
1.99											14.8365 −
2.00											14.9453 +

TABLE 7.[1]—*Discharges in cubic feet per second and acre-feet of rectangular weirs without end contractions and corrections for end contractions.*

Discharges for each foot in width of a rectangular weir without end contractions.			Number to be subtracted from cubic feet per second when weir of any width has two end contractions. (Half as much for each one of any number of such contractions.)	Discharges for each foot in width of a rectangular weir without end contractions.			Number to be subtracted from cubic feet per second when weir of any width has two end contractions. (Half as much for each one of any number of such contractions.)
Depth in feet	Cubic feet per second	Acre-feet		Depth in feet	Cubic feet per second.	Acre-feet.	
0.01	0.00333000	0.0005504 +	0.0000067	0.71	1.99219459	0.3292884 —	0.2828916
.02	.00911866	.0015568 +	.0000377	.72	2.03443108	.3362696 -	.2929680
.03	.01730319	.0028600 +	.0001039	.73	2.07696187	.3432995 —	.3032364
.04	.02664000	.0044033 +	.0002131	.74	2.11978499	.3503777	.3137282
.05	.03723054	.0061538 +	.0003723	.75	2.16289845	.3575039 -	.3244348
.06	.04891080	.0080894 -	.0005871	.76	2.20630029	.3646777 +	.3353577
.07	.06167229	.0101938 —	.0008634	.77	2.24998862	.3718989 +	.3464983
.08	.07534931	.0124544 +	.0012056	.78	2.29396157	.3791672 +	.3578581
.09	.08991000	.0148612	.0016184	.79	2.33821731	.3864822 —	.3694394
.10	.10530984	.0174066	.0021061	.80	2.38275404	.3938436 +	.3812407
.11	.12148797	.0200807	.0026727	.81	2.42757000	.4012512 +	.3932664
.12	.13842550	.0228802 +	.0033222	.82	2.47266347	.4087047 +	.4055169
.13	.15608431	.0257990 +	.0040582	.83	2.51803274	.4162038	.4179985
.14	.17443607	.0288324 +	.0048842	.84	2.56367615	.4237481 +	.4306976
.15	.19345652	.0319761 +	.0058037	.85	2.60959206	.4313375 +	.4436307
.16	.21312000	.0352264 +	.0068199	.86	2.65577886	.4389717 +	.4567941
.17	.23340901	.0385800 +	.0079359	.87	2.70223499	.4466504 +	.4701800
.18	.25430888	.0420337	.0091549	.88	2.74895887	.4543734	.4838169
.19	.27578754	.0455847 +	.0104799	.89	2.79594899	.4621403 +	.4976790
.20	.29784125	.0492305	.0119138	.90	2.84320384	.4699510 +	.5117768
.21	.32045952	.0529685 +	.0134598	.91	2.89072196	.4778053	.5261114
.22	.34361986	.0567967	.0151193	.92	2.93850189	.4857028	.5406843
.23	.36731274	.0607128 +	.0168964	.93	2.98654220	.4936433 +	.5554968
.24	.39152644	.0647151 +	.0187932	.94	3.03484150	.5016267	.5705501
.25	.41625000	.0688017	.0208125	.95	3.08339839	.5096526 +	.5858456
.26	.44147311	.0729708	.0229566	.96	3.13221152	.5177209 +	.6013845
.27	.46718606	.0772208 +	.0252281	.97	3.18127950	.5258313 +	.6171681
.28	.49337970	.0815504	.0276293	.98	3.23060118	.5339837	.6331978
.29	.52004537	.0859579 +	.0301627	.99	3.28017508	.5421777	.6494746
.30	.54717488	.0904421 +	.0328305	1.00	3.33000000	.5504132 +	.6660000
.31	.57476082	.0950017 +	.0356351	1.01	3.38007467	.5586900 +	.6827751
.32	.60279439	.0996354 +	.0385788	1.02	3.43039785	.5670079 +	.6998012
.33	.63126909	.1043421 +	.0416638	1.03	3.48096832	.5753667	.7170796
.34	.66018037	.1091207 +	.0448923	1.04	3.53178488	.5837661	.7346114
.35	.68951910	.1139701	.0482663	1.05	3.58284634	.5922060 +	.7523979
.36	.71928000	.1188893	.0517881	1.06	3.63415153	.6006862 +	.7704403
.37	.74945717	.1238772 +	.0554598	1.07	3.68569930	.6092065	.7887398
.38	.78004195	.1289330 +	.0592834	1.08	3.73748851	.6177667	.8072977
.39	.81103789	.1340558 +	.0632610	1.09	3.78951805	.6263666 +	.8261151
.40	.84243077	.1392448	.0673945	1.10	3.84178681	.6350061 —	.8451932
.41	.87421855	.1444989 +	.0716859	1.11	3.89429370	.6436849 +	.8645332
.42	.90638640	.1498176	.0761374	1.12	3.94703764	.6524029 +	.8841365
.43	.93893962	.1551999 +	.0807505	1.13	4.00001757	.6611599 +	.9040041
.44	.97193873	.1606452 +	.0855275	1.14	4.05323245	.6699558	.9241371
.45	1.00522136	.1661528 —	.0904702	1.15	4.10668124	.6787903	.9445368
.46	1.03891731	.1717219	.0955803	1.16	4.16036292	.6876633	.9652043
.47	1.07297850	.1773518 +	.1008599	1.17	4.21427650	.6965746 +	.9861408
.48	1.10740400	.1830420	.1063107	1.18	4.26842097	.7055241 +	1.0073475
.49	1.14219000	.1887917 +	.1119346	1.19	4.32279535	.7145116 +	1.0288254
.50	1.17738279	.1946003	.1177333	1.20	4.37739868	.7235370	1.0505758
.51	1.21282879	.2004676 -	.1237086	1.21	4.43223000	.7326000	1.0725997
.52	1.24867452	.2063925	.1298622	1.22	4.48728837	.7417006 —	1.0948984
.53	1.28486659	.2123746 +	.1361959	1.23	4.54257285	.7508385	1.1174730
.54	1.32140174	.2184135 +	.1427114	1.24	4.59808252	.7600136 +	1.1403245
.55	1.35827675	.2245086	.1494105	1.25	4.65381648	.7692259	1.1634541
.56	1.39548854	.2306493	.1562947	1.26	4.70977382	.7784750 +	1.1868629
.57	1.43303407	.2368651 +	.1633659	1.27	4.76595366	.7877609 +	1.2105521
.58	1.47091042	.2431257	.1706258	1.28	4.82235511	.7970835	1.2345228
.59	1.50911471	.2494404 +	.1780755	1.29	4.87897732	.8064425 +	1.2587760
.60	1.54764410	.2558089 +	.1857174	1.30	4.93581942	.8158379 +	1.2833128
.61	1.58649602	.2622307 +	.1935525	1.31	4.99288056	.8252695 +	1.3081344
.62	1.62566767	.2687054	.2015828	1.32	5.05015991	.8347372	1.3332419
.63	1.66515630	.2752325	.2098097	1.33	5.10765665	.8442408	1.3586364
.64	1.70496000	.2818116	.2182349	1.34	5.16536994	.8537802	1.3843190
.65	1.74507803	.2884423	.2268599	1.35	5.22329899	.8633552 +	1.4102904
.66	1.78550116	.2951242	.2356862	1.36	5.28144299	.8729658	1.4365522
.67	1.82623406	.3018569	.2447154	1.37	5.33980115	.8826118 -	1.4631053
.68	1.86727208	.3086400 +	.2539490	1.38	5.39837268	.8922930 +	1.4899507
.69	1.90861296	.3154732 +	.2633886	1.39	5.45715682	.9020094	[illegible]
.70	1.95025460	[illegible] +	.2730356	1.40	5.51615279	.9117606	[illegible]

[1] ...nd 6 were computed from Table 7.

TABLE 7.—*Discharges in cubic feet per second and acre-feet of rectangular weirs without end contractions and corrections for end contractions*—Continued.

Discharges for each foot in width of a rectangular weir without end contractions.			Number to be subtracted from cubic feet per second when weir of any width has two end contractions. (Half as much for each one of any number of such contractions.)	Discharges for each foot in width of a rectangular weir without end contractions.			Number to be subtracted from cubic feet per second when weir of any width has two end contractions. (Half as much for each one of any number of such contractions.)
Depth in feet.	Cubic feet per second.	Acre-feet.		Depth in feet.	Cubic feet per second.	Acre-feet.	
1.41	5.5753984	.9215471 –	1.5722513	1.71	7.4462634	1.2307874 –	2.5466215
1.42	5.6347722	.9313681 +	1.6002766	1.72	7.5116769	1.2415995 +	2.5840162
1.43	5.6940418	.9412238 +	1.6285995	1.73	7.5772809	1.2524431 +	2.6217385
1.44	5.7542400	.9511140 +	1.6572210	1.74	7.6430747	1.2633181 +	2.6597893
1.45	5.8142891	.9610387	1.6861123	1.75	7.7090578	1.2742244 +	2.6981695
1.46	5.8745329	.9709976 –	1.7153642	1.76	7.7752298	1.2851620 –	2.7368802
1.47	5.9349934	.9809906 –	1.7448880	1.77	7.8415903	1.2961306	2.7759223
1.48	5.9956737	.9910177 +	1.7747146	1.78	7.9081379	1.3071302 +	2.8152967
1.49	6.0565267	1.0010788	1.8048450	1.79	7.9748730	1.3181608 +	2.8550043
1.50	6.1176063	1.0111737	1.8352893	1.80	8.0417918	1.3292223	2.8950461
1.51	6.1787849	1.0213022 +	1.8660211	1.81	8.1089028	1.3403145 –	2.9354230
1.52	6.2403958	1.0314644	1.8970695	1.82	8.1761964	1.3514374 +	2.9761357
1.53	6.3020326	1.0416600 +	1.9284255	1.83	8.2436751	1.3625909 +	3.0171853
1.54	6.3639284	1.0518891	1.9600901	1.84	8.3113384	1.3737750	3.0585725
1.55	6.4260568	1.0621511	1.9920652	1.85	8.3791850	1.3849894 +	3.1002946
1.56	6.4883812	1.0724168	2.0243509	1.86	8.4472169	1.3962342 +	3.1423643
1.57	6.5507952	1.0827753	2.0569486	1.87	8.5154311	1.4075093	3.1847707
1.58	6.6134772	1.0931367 +	2.0898592	1.88	8.5838280	1.4188145 +	3.2275187
1.59	6.6768267	1.1035310 +	2.1230867	1.89	8.6524070	1.4301499 –	3.2706092
1.60	6.7394615	1.1139580 +	2.1566231	1.90	8.7211676	1.4415153 +	3.3140431
1.61	6.8027208	1.1244177	2.1904781	1.91	8.7901094	1.4529107	3.3578213
1.62	6.8662018	1.1349099	2.2246506	1.92	8.8592320	1.4643359	3.4019447
1.63	6.9298782	1.1454315 +	2.2591407	1.93	8.9285348	1.4757909	3.4464141
1.64	6.9937842	1.1559015	2.2939196	1.94	8.9980173	1.4872757	3.4912305
1.65	7.0578130	1.1665807	2.3290783	1.95	9.0676792	1.4987900	3.5363948
1.66	7.1220720	1.1772020	2.3645278	1.96	9.1375200	1.5103339	3.5819079
1.67	7.1865249	1.1878551	2.4002991	1.97	9.2075391	1.5219073	3.6277706
1.68	7.2511715	1.1985407	2.4363932	1.98	9.2777361	1.5335101 +	3.6739847
1.69	7.3160100	1.2092579	2.4728110	1.99	9.3481107	1.5451423 –	3.7205481
1.70	7.3810496	1.2200068	2.5095531	2.00	9.4186623	1.5568037 –	3.7674647

MEASURING FLUMES.

During the spring and summer of 1899 considerable time was occupied in rating flumes. Sufficient gagings were made of each flume to cover the variations in depths and discharges. In a number of the flumes rated it was found that the floor of the structure was below the grade of the ditch. Hence dead water existed in the flume when the discharge was zero. After the gagings were made, the notes giving the width of a cross section and the depths along it, together with the meter readings, were either computed in the field or sent to the Cheyenne office. Each gaging gives a depth and a corresponding discharge which define approximately a point on the rating curve when platted in rectangular coordinates. For convenience, the various depths of water are assumed to be the ordinates and the corresponding discharges the abscissas of the curve. If the points when platted on a convenient scale do not lie along or near a straight line or curve, it either shows inaccuracies in the gagings or faults in the construction of the flume. With the coordinates of the points observation equations can be written, and from these a mean mathematical curve can be computed.

The following method of reduction assumes that the general equation of a conic,

$$aq^2+2kqh+bh^2+2gq+2fh+c=0,$$

represents the relation between the depths h and the corresponding discharges q. The equation contains six constants, a, k, b, g, f, and c. Since it can be divided by any one of the constants without affecting the relation between q and h, there are only five conditions to be satisfied to determine the nature of the curve. Hence the results of the gagings, i. e., the depths and corresponding discharges, can be substituted for h and q in the general equation and the observation equation thus formed. The number of gagings, and consequently the number of such equations, generally exceeds six, the number of constants to be determined. They must therefore be reduced, preferably by the method of least squares, to six normal equations, which can be solved for the desired constants.

The resulting curve is usually hyperbolic. Owing to the fact that only a small portion of the curve is used, it is generally possible to find a parabola which will approximate it. Accordingly, a number of curves have been computed, using for the form of the observation equation

$$Q=ah^2+bh+c,$$

in which a, b, and c are constants. As this equation is the fundamental form of the parabola, the resulting curves are always parabolas. The computations are much simplified by making the approximation.

From the mathematical curve rating tables have been made which give the depths, with their corresponding discharges, from 0.01 of a foot to the greatest depth the flume will carry.

To show the method of rating flumes and preparing the rating tables, the results obtained at Mesa, Ariz., are given. Mr. W. H. Code had charge of the gagings. He sent the notes of his work to the office, where the rating curve was computed and a rating table was prepared.

Depths and corresponding discharges obtained from gagings of the Mesa Canal.

Depths.	Discharges per second.	Depth.	Discharges per second.
Feet.	*Cubic feet.*	*Feet.*	*Cubic feet.*
0.59	7.50	1.25	33.75
.66	9.38	1.31	36.56
.72	11.60	1.38	39.80
.79	13.80	1.44	43.80
.85	16.30	1.51	48.30
.92	19.07	1.57	53.60
.98	22.07	1.64	59.58
1.05	25.25	1.97	85.00
1.12	28.25	2.29	115.00
1.18	31.00	2.62	145.00

From these coordinates, the equation $Q=21.256h^2+.8502h+.0004$ was computed. Q and h have the same values as before given in the general equation for the discharge of measuring flumes. The third term in the second member can be omitted, as it is too small to affect

the results. It represents the discharge when h is zero, and indicates that leakage around the flume was small. From this equation a rating table was computed for depths ranging from 0.01 of a foot to the maximum depth carried by the canal. A table was first prepared giving the results in cubic feet per second. It was afterwards reduced, as in the case of weir tables, to corresponding discharges in acre-feet for periods of two hours. The accompanying diagram (fig. 11) indicates how closely the gagings made by Mr. Code agree with the computed curve.

As tables of this character have no value except with reference to the flume to which they relate, they are not given in this report. However, when it is considered that about one-half of the stations maintained during the season of 1899 employed measuring flumes, the work of preparing the rating tables can be appreciated. The results obtained from flume ratings have served to show that but few points are needed to determine the nature of the discharge curve. For this

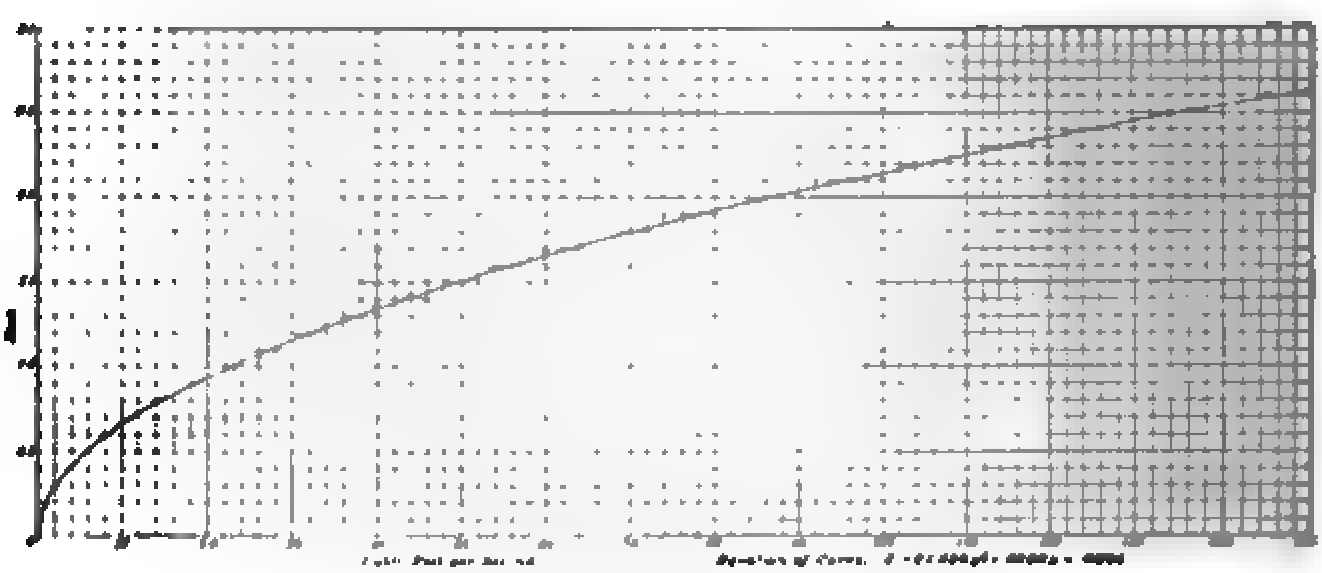


FIG. 11.—Discharge curve for the Mesa Canal, Mesa, Ariz.

reason it is better to make gagings which will accurately fix five or six points in the curve, rather than to have a great many gagings scattered along for various depths. If, while the depth is the same, the flume is gaged three or four times, each result checks the others, and the point on the curve for that depth is accurately located. In a number of flumes the discharge was zero when the depth was as great as a foot. In others there was a discharge when the depth was zero. As the radius of curvature of the discharge curve is short for small depths, it is important that a number of points be determined there.

REDUCTION OF REGISTER SHEETS.

After the rating tables and weir tables had been prepared, the register sheets were taken up for computation. The sheets show the depths on a natural scale, and the mean depth for two-hour periods can be seen at a glance. Noting the depth for each of these periods,

the tables give the corresponding discharge in either cubic feet per second or acre-feet for that period. The discharges for each two-hour period of each day were added, and this sum was written on the sheet. After the season had been completed for each station, the sheets were again taken up and a table was prepared giving the discharge for each day during the irrigation season. This finished the first step in the determination of the duty of water for the canal or lateral in question. It was only necessary to find the area of land irrigated, and secure a record of the rainfall, to be able to prepare diagrams showing the results of the work graphically.

DIAGRAMS.

While the tables give all the information obtained relative to the volume of water used from canals and laterals, yet they require considerable study before they can be comprehended. It is almost impossible to understand the fluctuations as shown by the figures of the tables, or to compare the volume of water discharged during different days, unless it is all placed so that it can be understood at a glance. It was also desired to show the rainfall for each month, and if possible to determine the effect it has on the depth to which land is covered by irrigation during the same period. Diagrams were therefore drawn to show the tables graphically and the depth of water applied to the land each month by irrigation and rainfall. As the drawings have to conform to the dimensions of the printed page, the information which the diagrams are intended to show is not exhibited to the best advantage. Another factor which had to be taken into consideration in preparing the drawings was that the irrigation season varies at almost every station. At the southern stations, including New Mexico, Arizona, and California, irrigation is practiced throughout the year; hence the diagrams have been drawn to include a twelve-month period. The irrigation season in Northern States varies greatly, but to make the diagrams uniform a six-months period, beginning April 1, has been assumed. It only needs a glance at the diagrams to show that the season when water is used in the Northern States does not cover the periods allowed for them. Time divisions are measured by horizontal lines, and divisions showing the volume of water used or delivered in acre-feet are measured on vertical lines. For the southern stations a day space is equal to 3/160 of an inch, and for northern stations a day space is 3/80 of an inch. The months are designated by name at the top of the diagram, and under them are the numbers 10 and 20 in the Southern and 5, 10, 15, 20, 25, and sometimes 30, in the Northern States. Any intervening day can be easily located. The vertical or volume scale varies in every case. This fact should be borne in mind when comparing the quantity of water used in dif-

ferent localities, and the scale of acre-feet at the left of the drawing should be examined before the study of the diagram is begun. In each day space during the irrigation season is a column which stands vertically at a height on the acre-foot scale equal to the discharge for that day. The sum of the columns for each day of the irrigation period gives the total volume discharged by the ditch or canal in acre-feet.

When this volume in acre-feet is divided by the number of acres irrigated, the result is the equivalent depth to which the land would be covered in feet. Add the precipitation in feet to this, and the result is the total equivalent depth to which the land would be covered. This summary is shown in the column at the right of the discharge diagram. The depth supplied by irrigation is represented by black areas, while the rainfall is designated by hatched areas. A special scale is made for this column, and it should not be confused with the acre-feet scale at the left of the diagram.

The diagrams show that there is a great fluctuation in the daily discharges at each station. The register sheets show more. The discharge not only varies for different days, but it changes more or less each hour. A diagram made up of the discharges for each two-hour period would represent a curved instead of an irregular appearance. Many of the diagrams have special features which need explanation. Some unusual fluctuations occurred which were evidently brought about by the demands made upon the volume by the irrigators. Each station will be taken up, therefore, and the important features as exhibited by the discharge diagrams will be briefly described.

DIAGRAMS SHOWING USE OF WATER NEAR CARLSBAD, N. MEX.

(PLATES IV AND V.)

Plate IV shows the volume of water used from the Pecos Canal, New Mexico. This station keeps a continuous record of all water used from the canal on the west side of the river. Some irrigation was accomplished before the station was installed, and irrigation was necessary when the season's report was made. However, the diagram shows approximately the volume of water necessary for the growth and maturity of the crops. The discharge of the canal was regulated so as to provide only the water delivered to the irrigators, so that but little ran to waste at its lower terminus.

The register was installed on April 16. The discharge for that day corresponding to the record of depths furnished by it was 181 acre-feet. The volume decreased each day after that date until the 22d, when the discharge began to increase. On the 3d of May the discharge increased from 181 to over 299 acre-feet. From this date until the 9th of July the demand for water was steady and the volume flowing in the canal had no important fluctuations. Water was turned out of

DIAGRAM SHOWING THE USE OF WATER NEAR CARLSBAD, N. MEX.

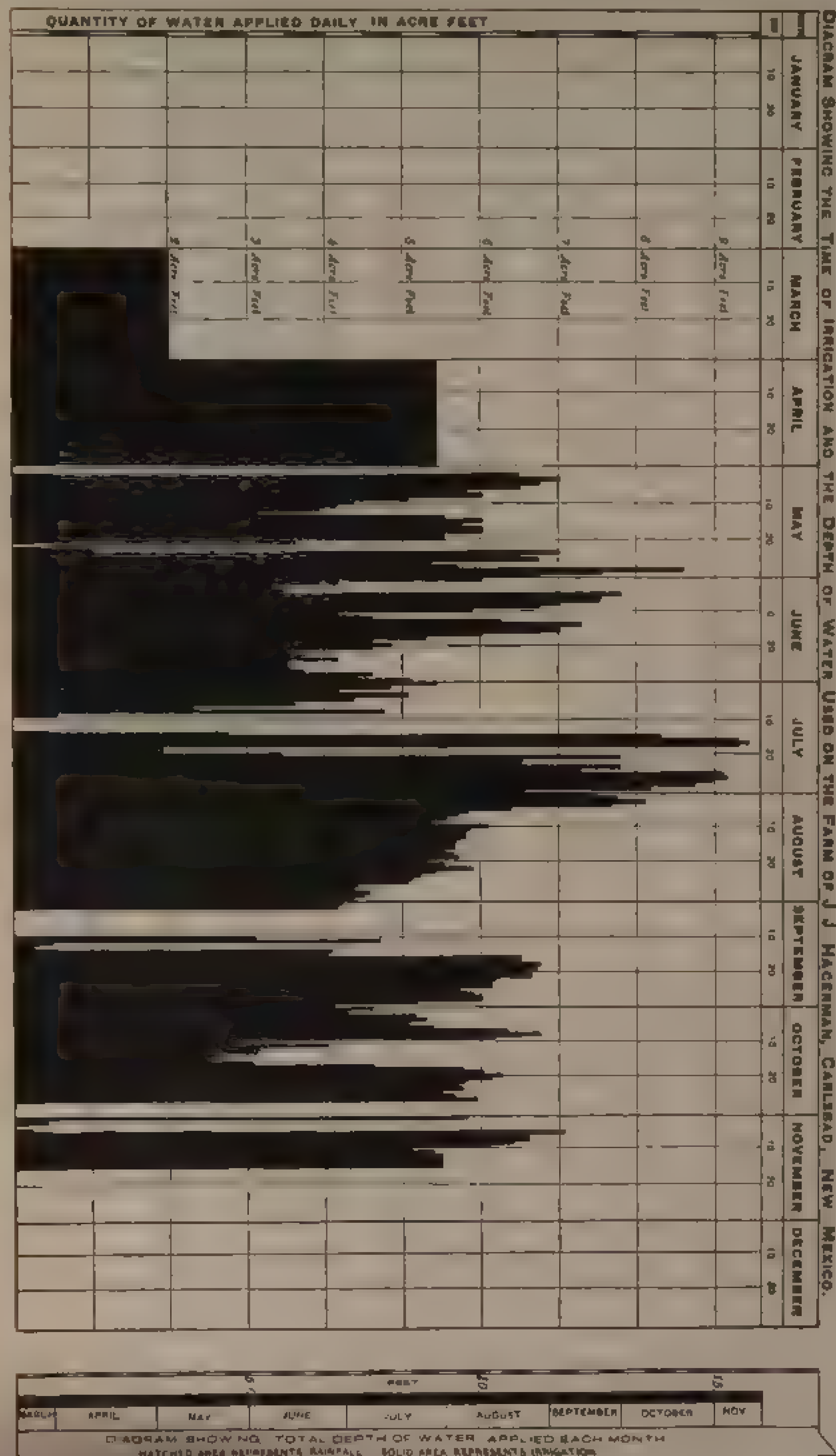


DIAGRAM SHOWING THE USE OF WATER ON HAGERMAN FARM, NEAR CARLSBAD, N. MEX.

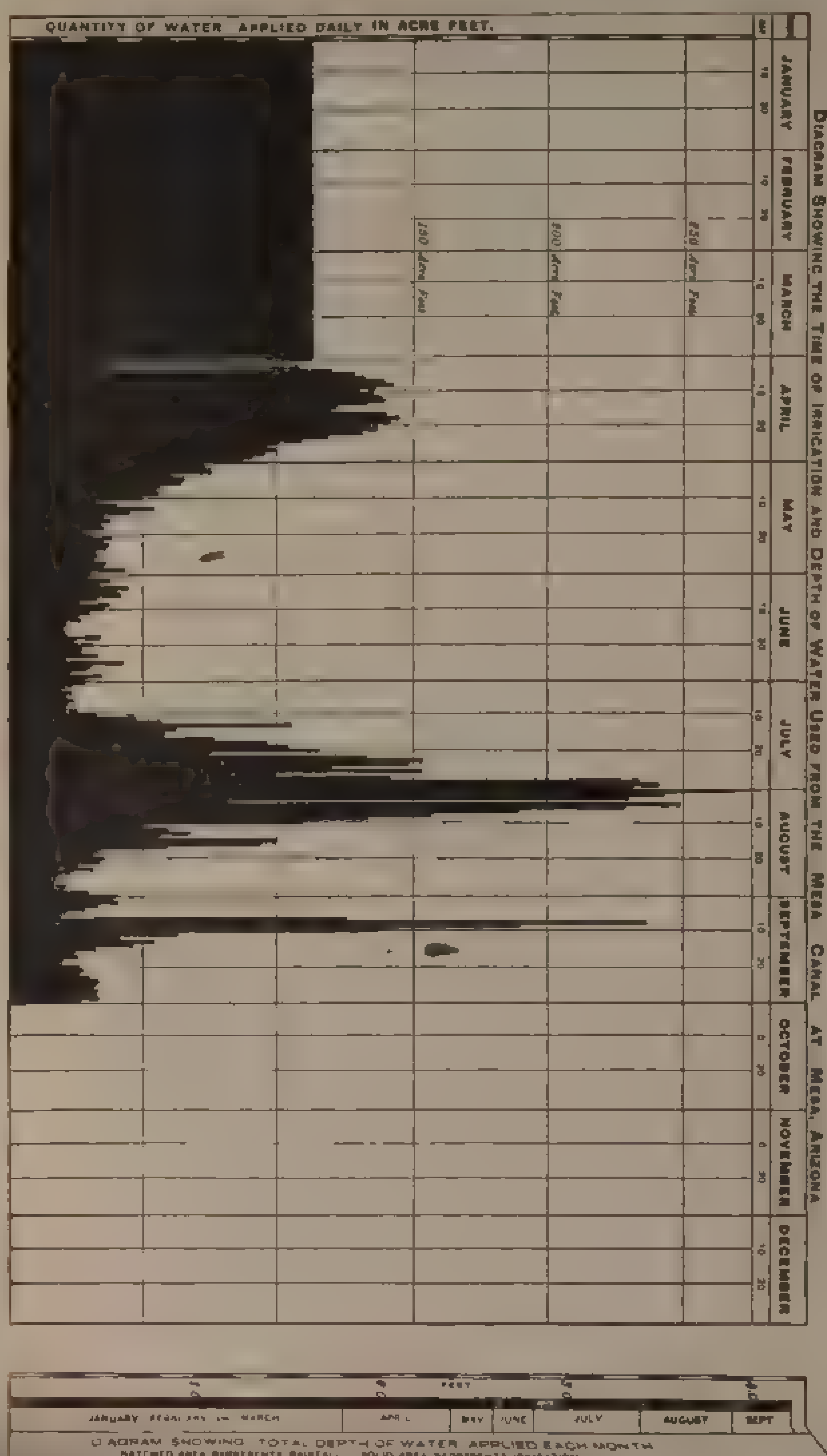


DIAGRAM SHOWING THE USE OF WATER NEAR MESA, ARIZ.

the canal then so that the channel might be repaired. Water was again turned into the canal on the 12th, and on the 14th the canal carried the maximum volume for any day of the irrigation season. After being deprived of water for several days, the irrigators demanded a large volume. The low points shown in the discharge diagram generally follow rains.

It will be noticed in the column to the right that enough water passed the measuring station, including rainfall, to cover the entire area on the west side of the river to a depth of 7 feet. No rainfall occurred during May and August, and but little during June or July. By referring to the first portion of the diagram it can be seen that the volume of the water used was affected by precipitation, and the column at the right shows that the quantity of water needed each month is about the same when rainfall is included.

The water used during the season of 1899 at this station was in excess of the normal volume needed. The driest season ever known in the valley occurred during that year; the river was lower, and the reservoirs were not filled when irrigation began.

The second station at Carlsbad was installed for the purpose of determining the quantity of water required in irrigation when the loss in transportation was eliminated. Plate V shows the volumes used each day, and the equivalent depth to which the land was covered by water. The farm selected is located near Carlsbad, on the east side of the river. The land is high, the soil is sandy, and owing to the scarcity of vegetation the water receives the direct rays of the sun throughout the day In addition, the ditch is crooked and of considerable length. For these reasons the loss from seepage and evaporation is excessive, and the soil needs almost constant irrigation to produce crops. The ditch is only 4 or 5 feet wide and about a foot deep. Hence the fluctuations in its discharge are greater than those of the main canal. Yet the two diagrams are somewhat similar. Both show that August is the month when the greatest demand for water is felt, and many of the important fluctuations in the discharge of the canal can be seen in the diagram of this lateral. During the early part of September the ditch broke above the weir, and the channel was dry for a short time. During March and April the record was kept only close enough to form an estimate of the volume of water used. Hence the total volume is inserted for these two months, and no attempt is made to show the fluctuations which occurred each day.

DIAGRAM SHOWING USE OF WATER NEAR MESA, ARIZ.

(PLATE VI.)

The diagram is similar to that for the Pecos Canal, inasmuch as it begins and ends abruptly, showing that water was used before and after the measurements were made. However, the greatest demand

was felt during the months covered by the measurements. The record from January 1 to March 31, inclusive, was kept by daily gage-rod readings. The total discharge is shown for that period regardless of the daily fluctuations. The small discharge shown in May, June, and a portion of July is due to a shortage of water in the Salt River, from which the canal is taken. As the river increased its discharge the canal received more water, until on the 1st day of August it carried 268.2975 acre-feet. Later the discharge of the canal receded with that of the river, only to rise again in September when rains furnished an additional supply. The great fluctuations shown by this diagram are unusual in canals of the dimensions of the Mesa Canal, and can be explained only by the fact that its supply varied with the volume carried by the river. The column to the right shows the variation in the use of water for different months. It will be seen that the depth to which the land is covered during May and June together is about two-thirds of that for April. A comparison of the discharge diagrams of the Mesa Canal and that of the Pecos Canal will serve to show the difference in use when the supply is ample and when it is insufficient. The conditions at the two places are quite similar, and yet, while the Pecos Canal afforded a supply sufficient to cover the land irrigated by it to a depth of 7 feet, the Mesa Canal furnished only enough to cover the land lying below it to a depth of 4.2 feet. The depth of the rainfall is included in both.

DIAGRAMS SHOWING USE OF WATER NEAR RIVERSIDE, CAL.

(PLATES VII, VIII, AND IX.)

Three stations were maintained on the Gage Canal near Riverside, Cal. It receives its water supply from the Santa Ana River, and the irrigated land was divided into three districts and a station installed where the canal enters each district. All of the water furnished by the canal was measured at station No. 1. At station No. 2 the water left after deducting that needed for the irrigation of district No. 1 was measured, and the remaining discharge of the canal after supplying district No. 2 was measured at station No. 3. The fluctuations in discharge of large and small volumes of water are shown clearly by these three diagrams. It will be seen that as the discharge decreases the fluctuations increase. As the canal is cemented, all the loss between the stations is due to evaporation. The rainy season in this locality occurs in December, January, and February. An examination of the diagrams will show that during this period the demand for water is at a minimum. The vertical or volume scales for stations No. 1 and No. 2 are nearly the same, while for station No. 3 the scale is seven times as great. A comparison between these diagrams and the one furnished by the measurements made in New Mexico shows the difference between

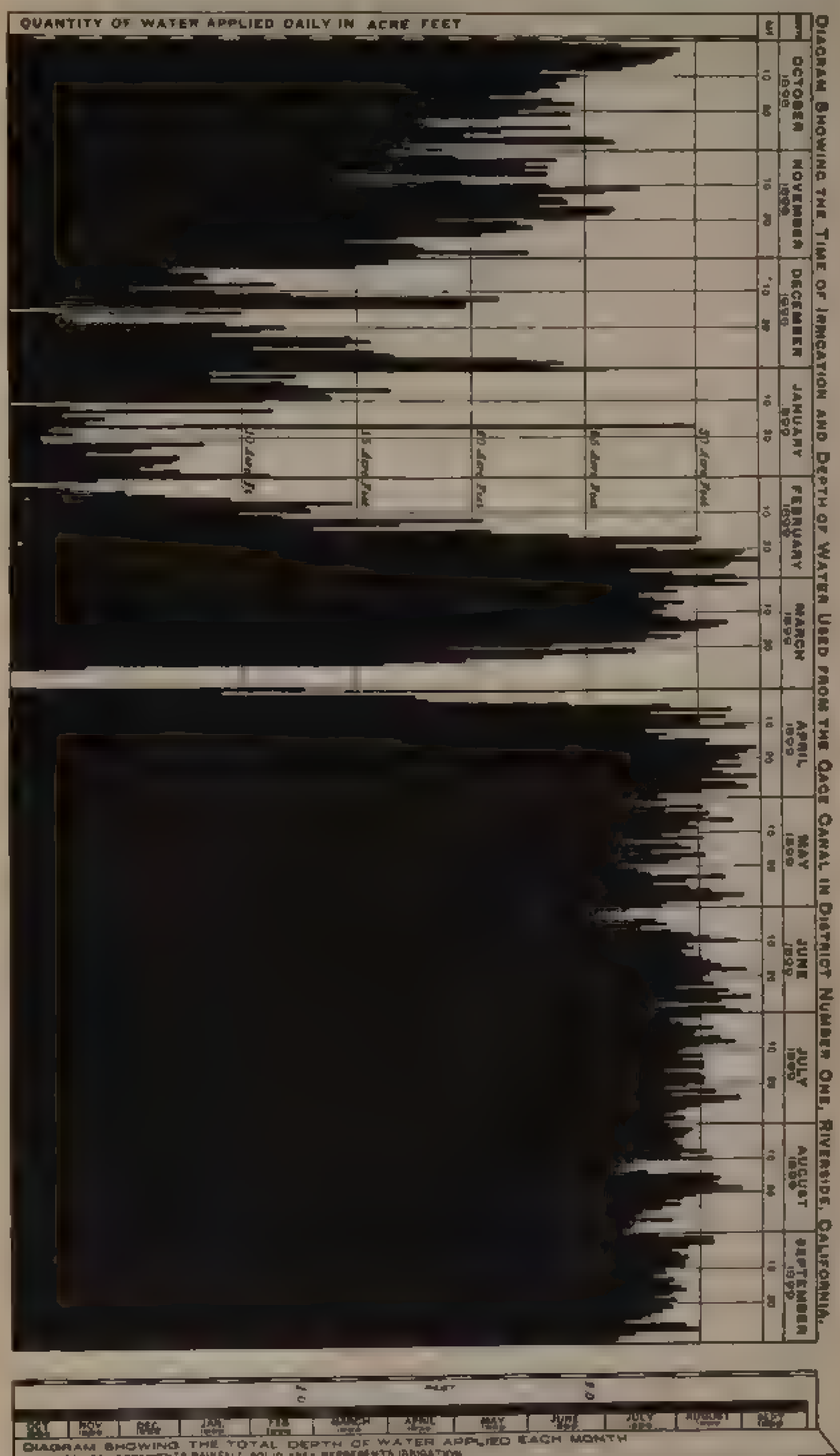


DIAGRAM SHOWING THE USE OF WATER NEAR RIVERSIDE, CAL., DISTRICT NO. 1.

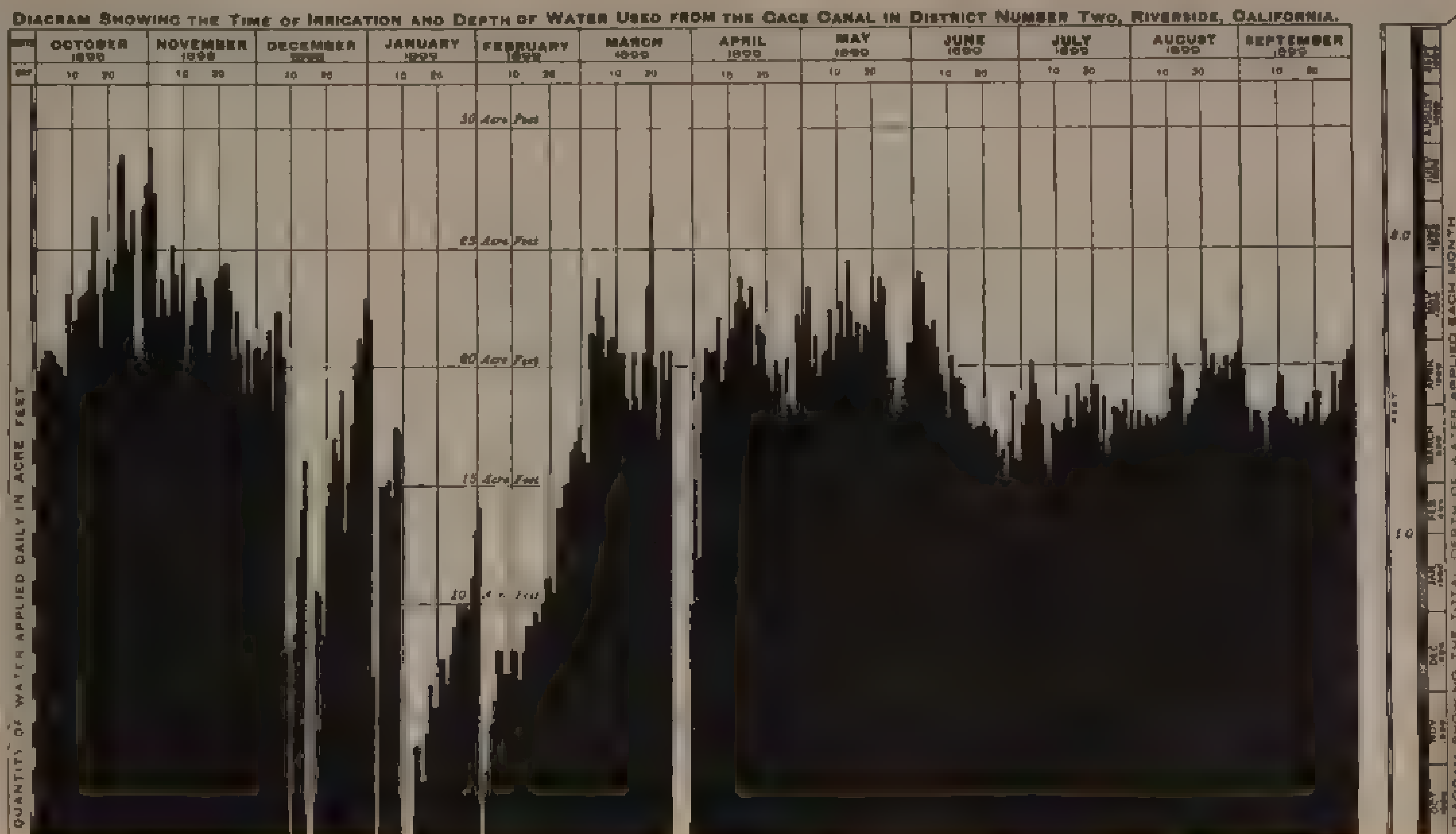
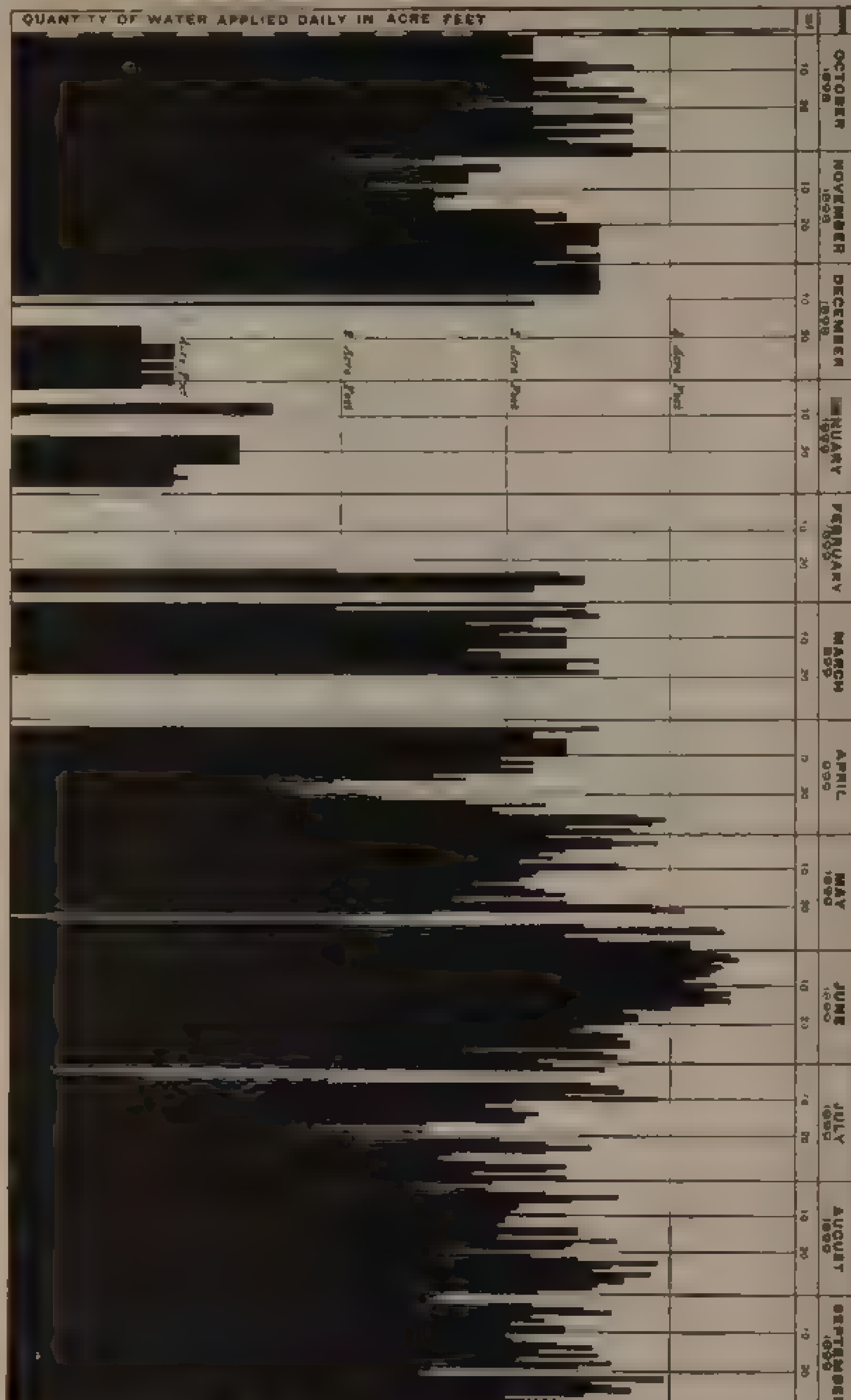


DIAGRAM SHOWING THE USE OF WATER NEAR RIVERSIDE, CAL., DISTRICT NO. 2.

DIAGRAM SHOWING THE TIME OF IRRIGATION AND DEPTH OF WATER USED FROM THE GAGE CANAL IN DISTRICT NUMBER THREE, RIVERSIDE, CALIFORNIA.



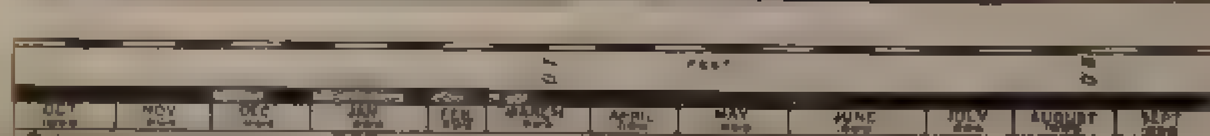


DIAGRAM SHOWING THE TOTAL DEPTH OF WATER APPLIED EACH MONTH
HATCHED AREA REPRESENTS RAINFALL. SOLID AREA REPRESENTS IRRIGATION.

DIAGRAM SHOWING THE USE OF WATER NEAR RIVERSIDE, CAL., DISTRICT NO. 3.

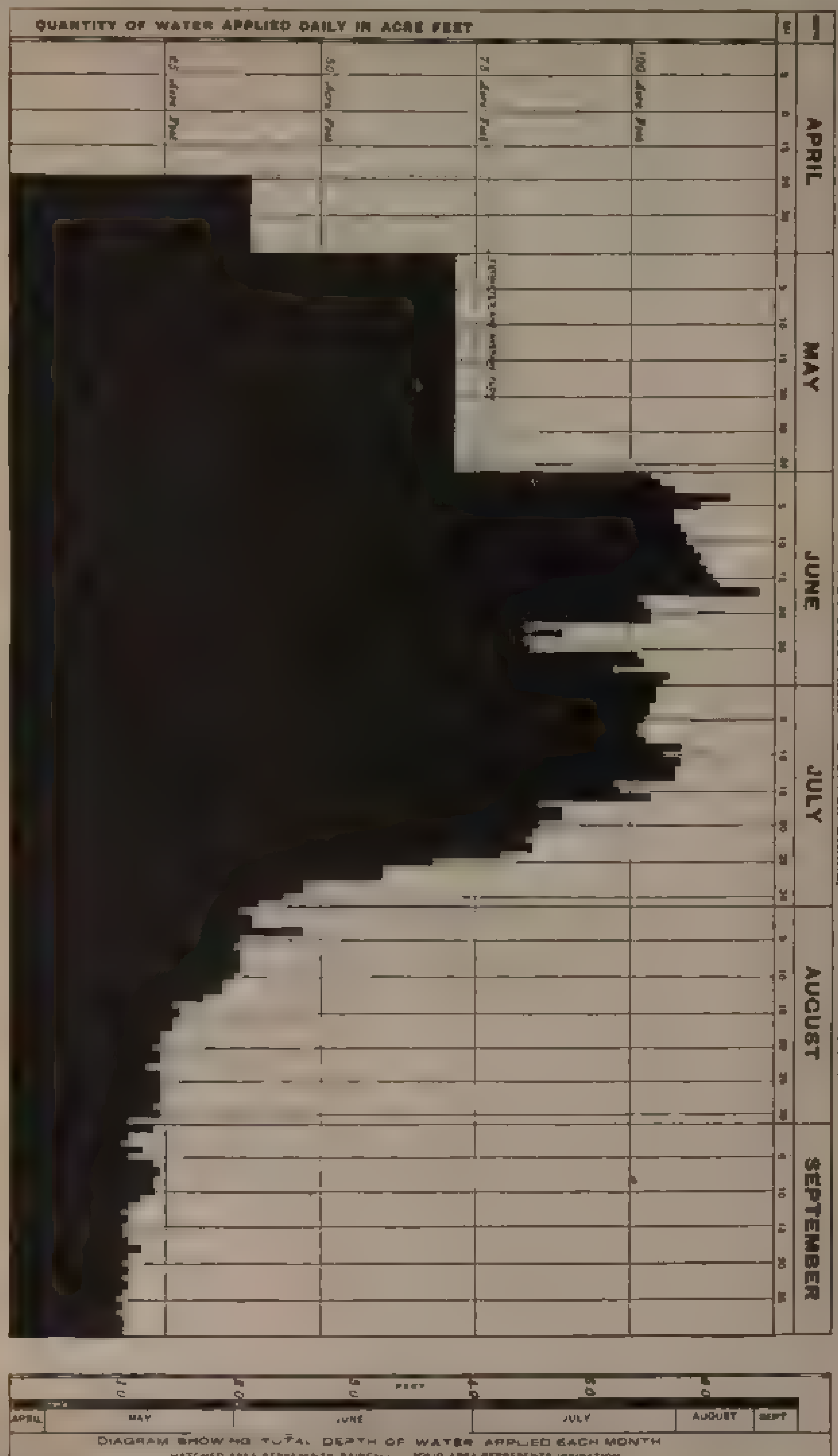


DIAGRAM SHOWING THE USE OF WATER UNDER THE UPPER CANAL, SALT LAKE CITY, UTAH.

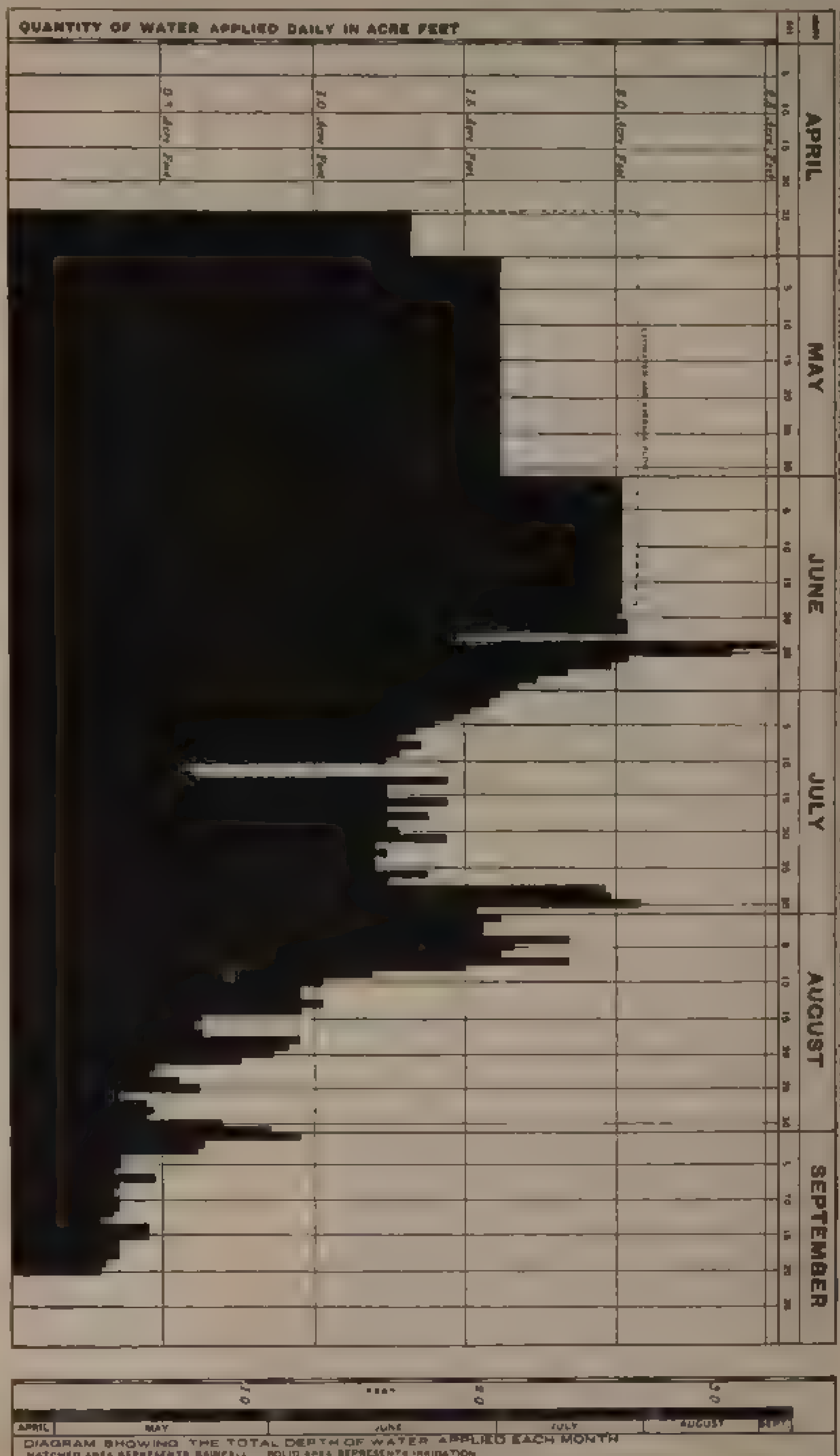


DIAGRAM SHOWING THE USE OF WATER UNDER THE LOWER CANAL, SALT LAKE CITY, UTAH.

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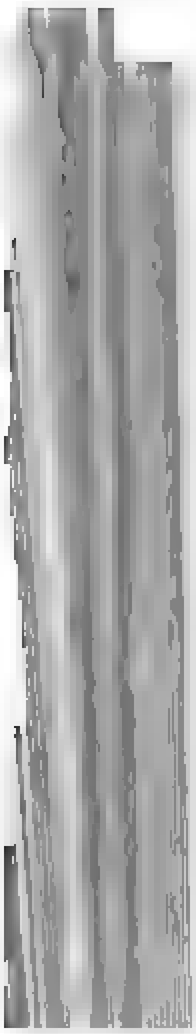

Diagram Showing the Use of Water under the Brown and Sanford Ditch, Salt Lake City, Utah.

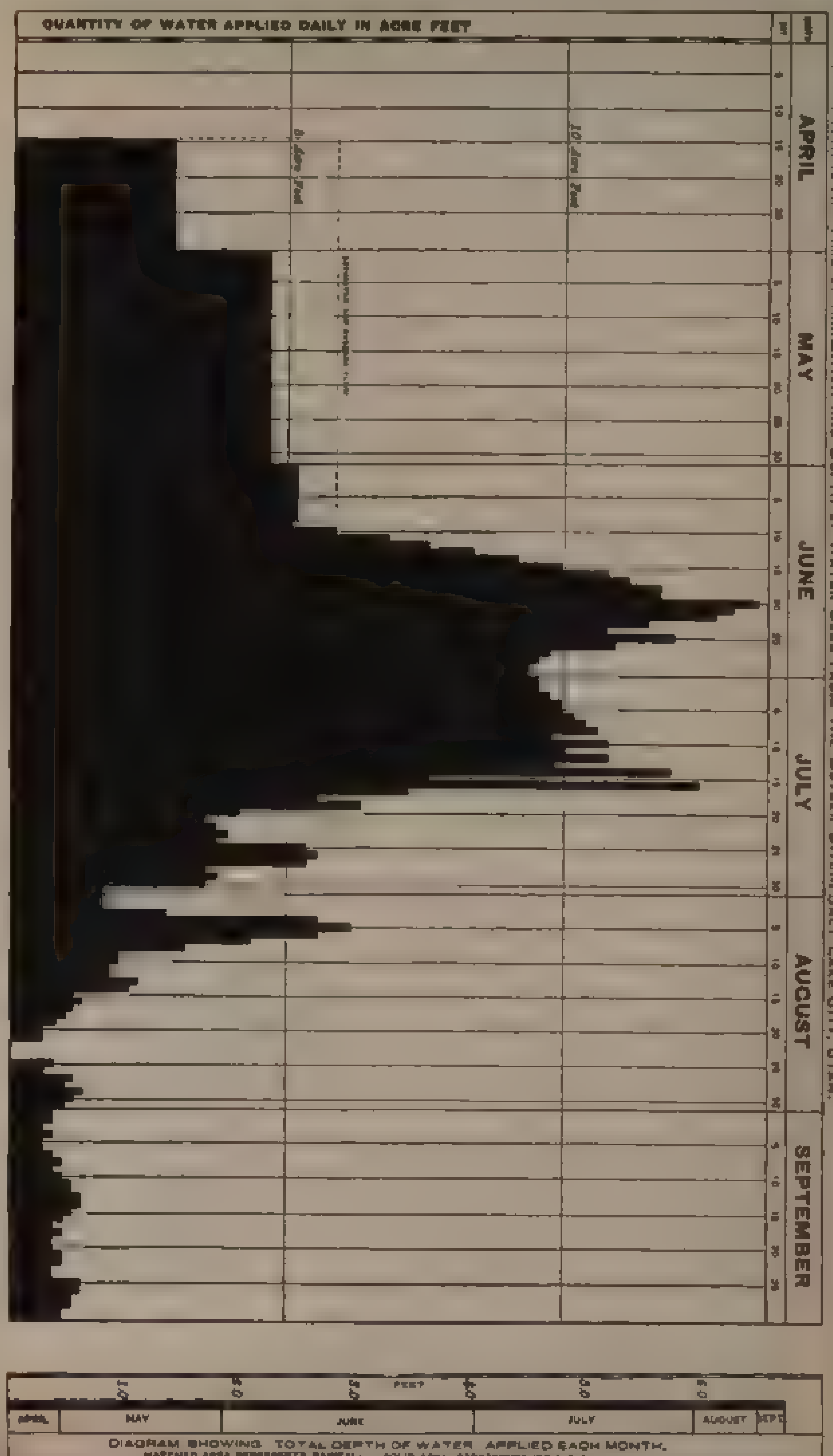

DIAGRAM SHOWING THE USE OF WATER UNDER THE BUTLER DITCH, SALT LAKE CITY, UTAH.

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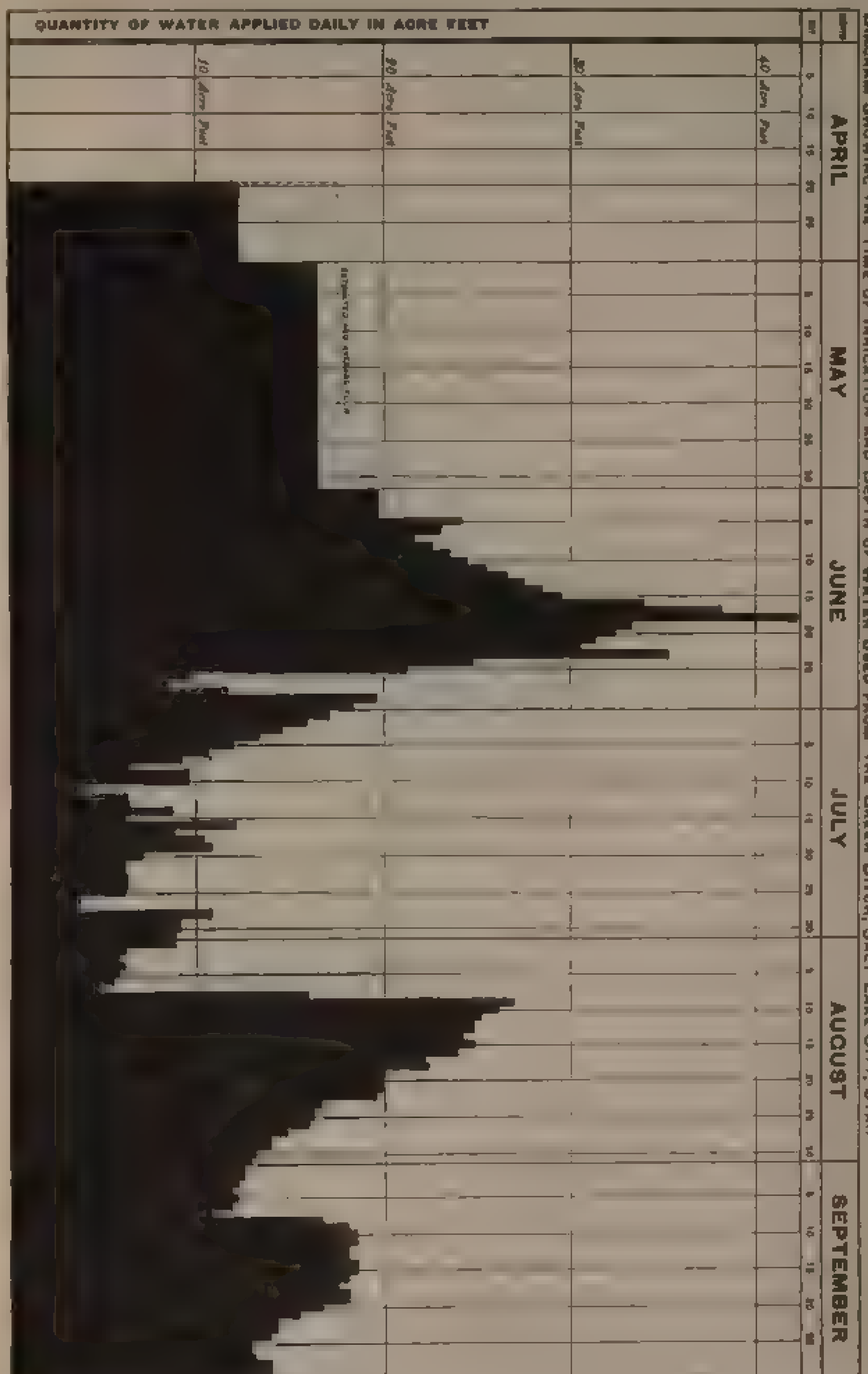


DIAGRAM SHOWING THE USE OF WATER UNDER THE GREEN DITCH, SALT LAKE CITY, UTAH.

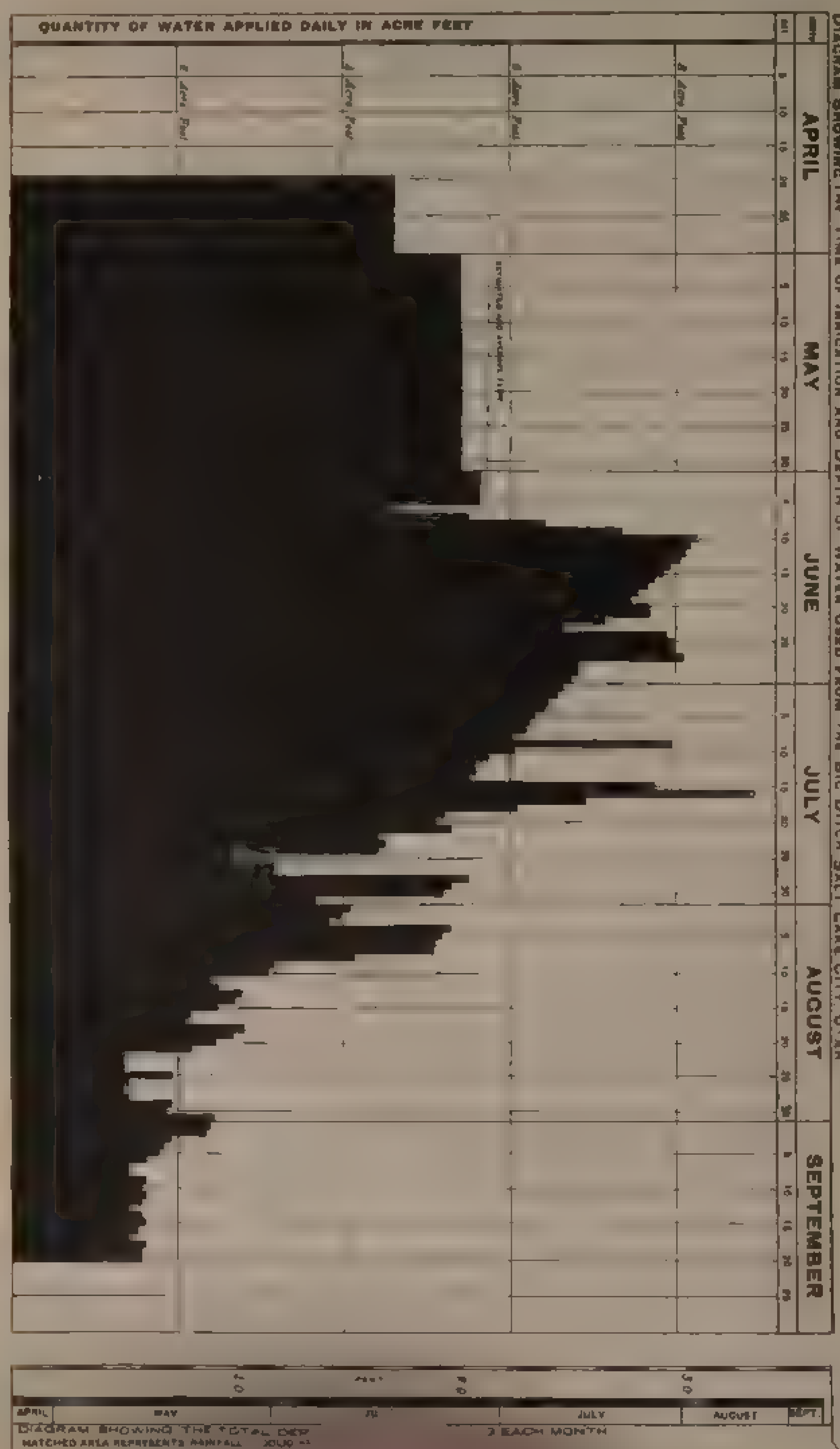


DIAGRAM SHOWING THE USE OF WATER UNDER THE BIG DITCH, SALT LAKE CITY, UTAH.

the economical and wasteful use of water. The climatic conditions are somewhat similar, yet the same quantity of water in California is spread over three times as much land as it was made to cover in New Mexico. When canals are cemented and a large portion of the water is delivered therefrom in pipes, losses are in a large measure prevented. If all localities, regardless of climatic conditions, were to adopt the same precautions for preventing waste as have been installed on the Gage Canal, there is no reason to predict a great variation in the duty of water aside from that which results from the different demands made by various crops and soils. At present the supply furnished by the Pecos River is ample, while in California there is a demand for every available cubic foot of water. The Gage Canal discharged sufficient water to cover the land under it to an equivalent depth of 2.71 feet, including rainfall. The record runs from October, 1898, to September, 1899. During a period of less than six months, beginning with April 15 and ending September 30, the Pecos Canal furnished enough water to cover the land under it to a depth of 7 feet, including rainfall. It is interesting to note that the volume of water needed each month from the Gage Canal is practically the same. The rainfall during the winter months, added to the volume of irrigation, makes the depth during that season equal to that for each of the remaining nine months.

DIAGRAMS SHOWING USE OF WATER FROM BIG COTTONWOOD CREEK, UTAH.

(Plates X, XI, XII, XIII, XIV, and XV.)

The diagrams for each locality where measurements have been kept exhibit special features. The diagrams showing the discharge of canals taking water from Big Cottonwood Creek in Utah are characteristic for that State. The irrigation season covers the same period on each, and the demand for water varies uniformly in all but one. The exception is the Green Ditch, which experienced a shortage of water during the latter part of June and throughout July. It used more water proportionally later in the season than any of the others.

Weirs were used exclusively in all of these canals, and readings of the depth of water flowing over them were made as often as possible by the water masters. The record for April and May has been estimated. The columns at the right of each diagram show that the equivalent depths that the various canals would have covered the land under them varies from 3.32 feet to 6.79 feet. The land on which the greatest depth of water was applied is supplied by the largest canal.

A comparison between these diagrams and those for the southern stations shows that the demand for water is much different during the irrigation season. June and July are the months of maximum use.

April, August, and September are the months when only small quantities are needed, and if the records were carried throughout the year the remaining six months, beginning with October 1, would show practically no discharge.

DIAGRAMS SHOWING USE OF WATER NEAR LOGAN, UTAH.

(PLATES XVI AND XVII.)

Plate XVI shows the results of the measurements made of the discharge of the Logan and Richmond Canal. It has the same general form as have all the diagrams for northern stations, and it is very much like those showing the discharge of the canals taking water from Big Cottonwood Creek, Utah. Water was turned into the canal early in June. The volume was gradually increased until the middle of July, when the demand was at its maximum. By the middle of August the discharge of the canal was small. The demand increased toward the end of August for the irrigation of late crops and meadow land.

In studying the discharge diagram of a main canal there is a tendency to believe that each irrigator used water continuously and that the quantity of water used fluctuated with the precipitation and the crop irrigated. That this is not the case is shown by Plate XVII, which indicates the volume of water needed and the time when irrigation was necessary for a farm under a lateral from the main canal. Irrigation began on June 20 and was carried on until June 23. No water was used after that until July 9, when irrigation was commenced and continued until the 15th. From that date until August 17 no water was used. The third irrigation occurred between August 16 and August 22.

DIAGRAMS SHOWING USE OF WATER NEAR LAMAR, COLO.

(PLATES XVIII AND XIX.)

The investigation to determine the duty of water in Colorado has been carried on under the irrigation system of the Great Plains Water Company, which takes its supply of water from the Arkansas River. The Amity Canal, whose headgate is near the town of Lamar, was selected for the measurements. While the canal is one of the longest in Colorado, yet the fluctuations in its discharge, as shown by Plate XVIII, are rapid. This can be explained by the scanty supply furnished by the river. The diagram for Amity Canal is similar to that for the Mesa Canal in Arizona in this respect. The demands of the irrigators were in excess of the volume of water available throughout the season. If the reservoirs belonging to this system had been filled, the diagram would have had a much different appearance and would have represented the volume of water needed rather than the volume flowing in the river at the canal's headgate. During the latter r
July no water was available.

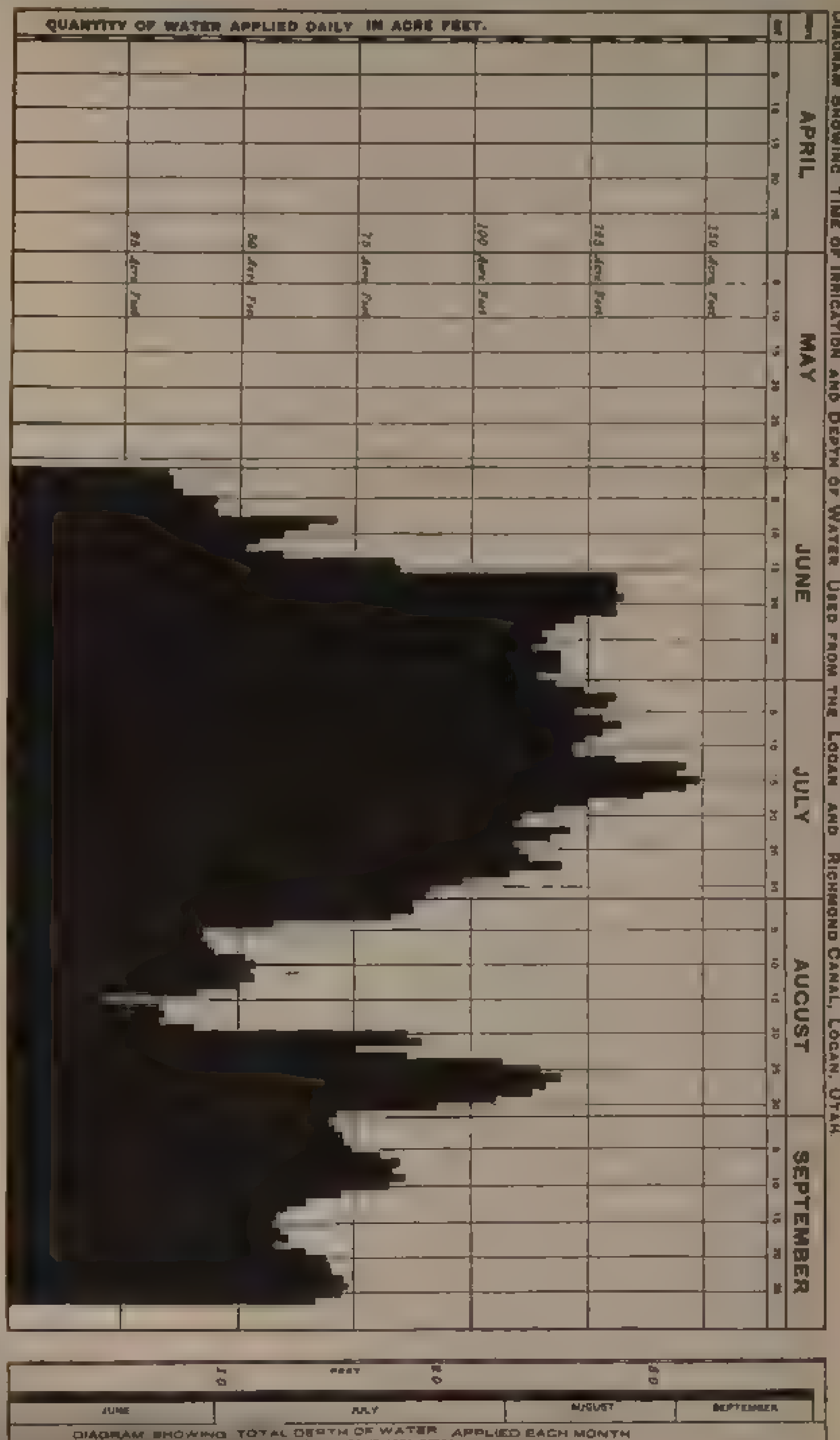


DIAGRAM SHOWING THE USE OF WATER AT LOGAN, UTAH.

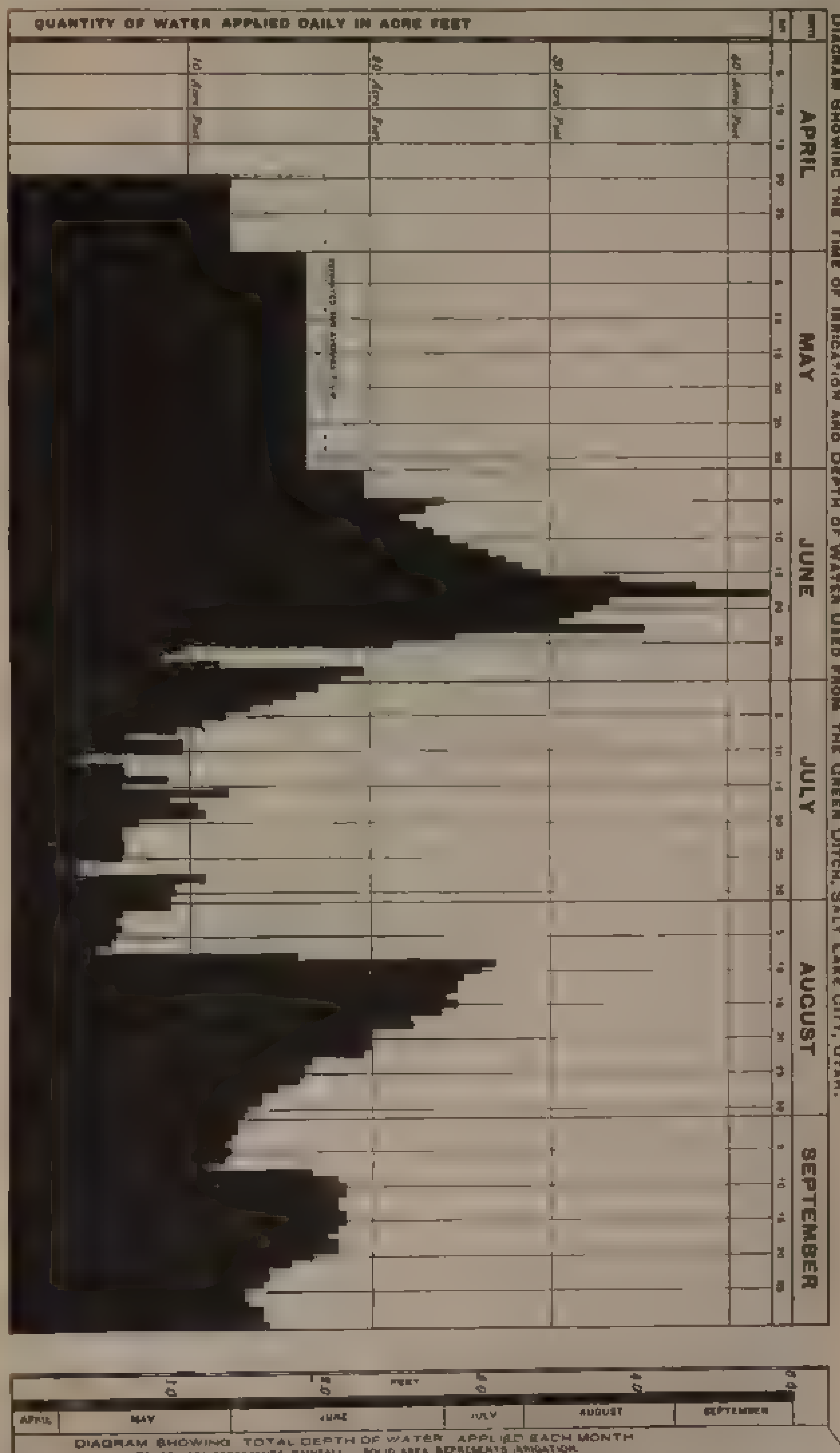
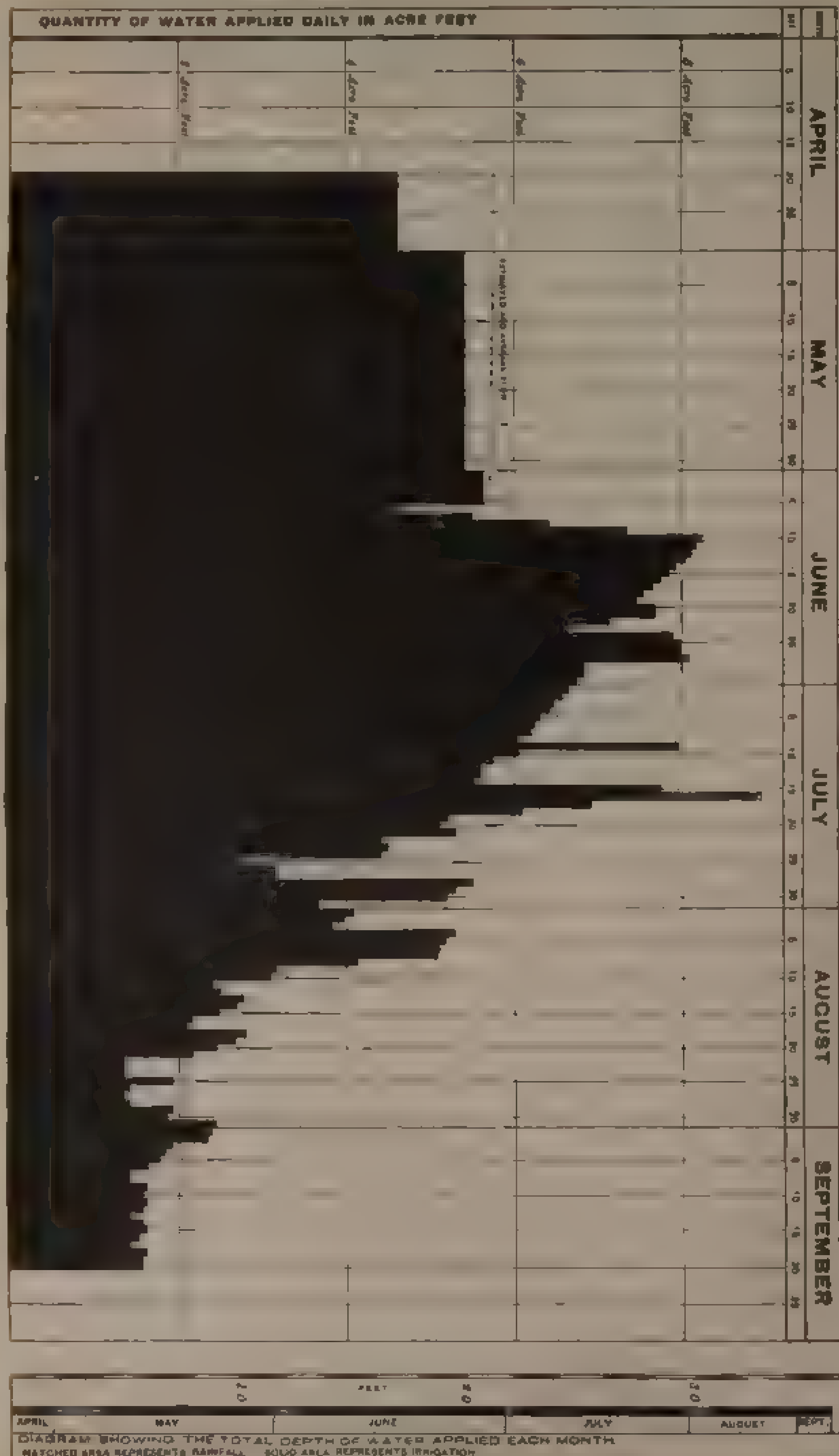


DIAGRAM SHOWING THE USE OF WATER UNDER THE GREEN DITCH, SALT LAKE CITY, UTAH.



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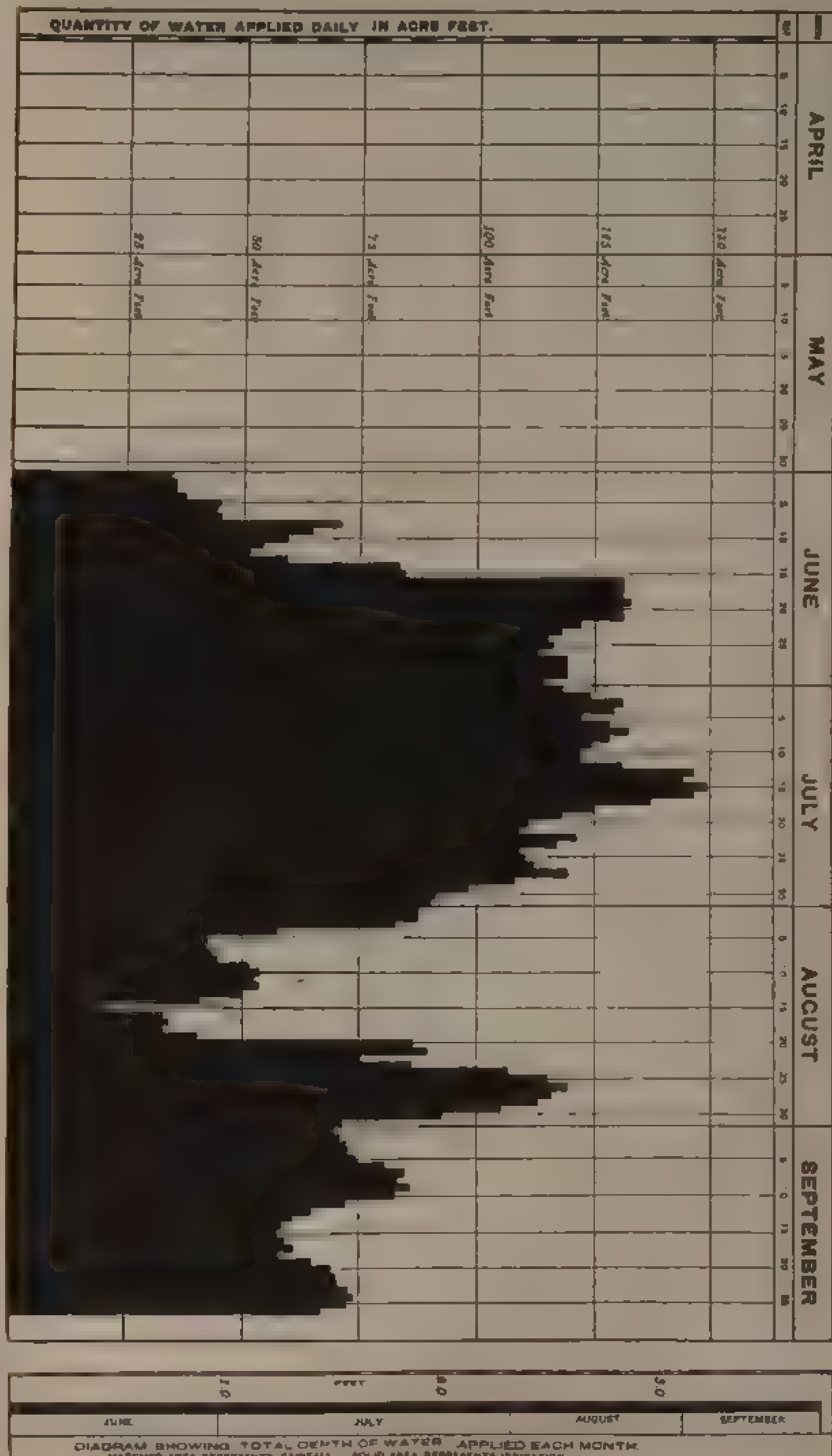


DIAGRAM SHOWING THE USE OF WATER AT LOGAN, UTAH.

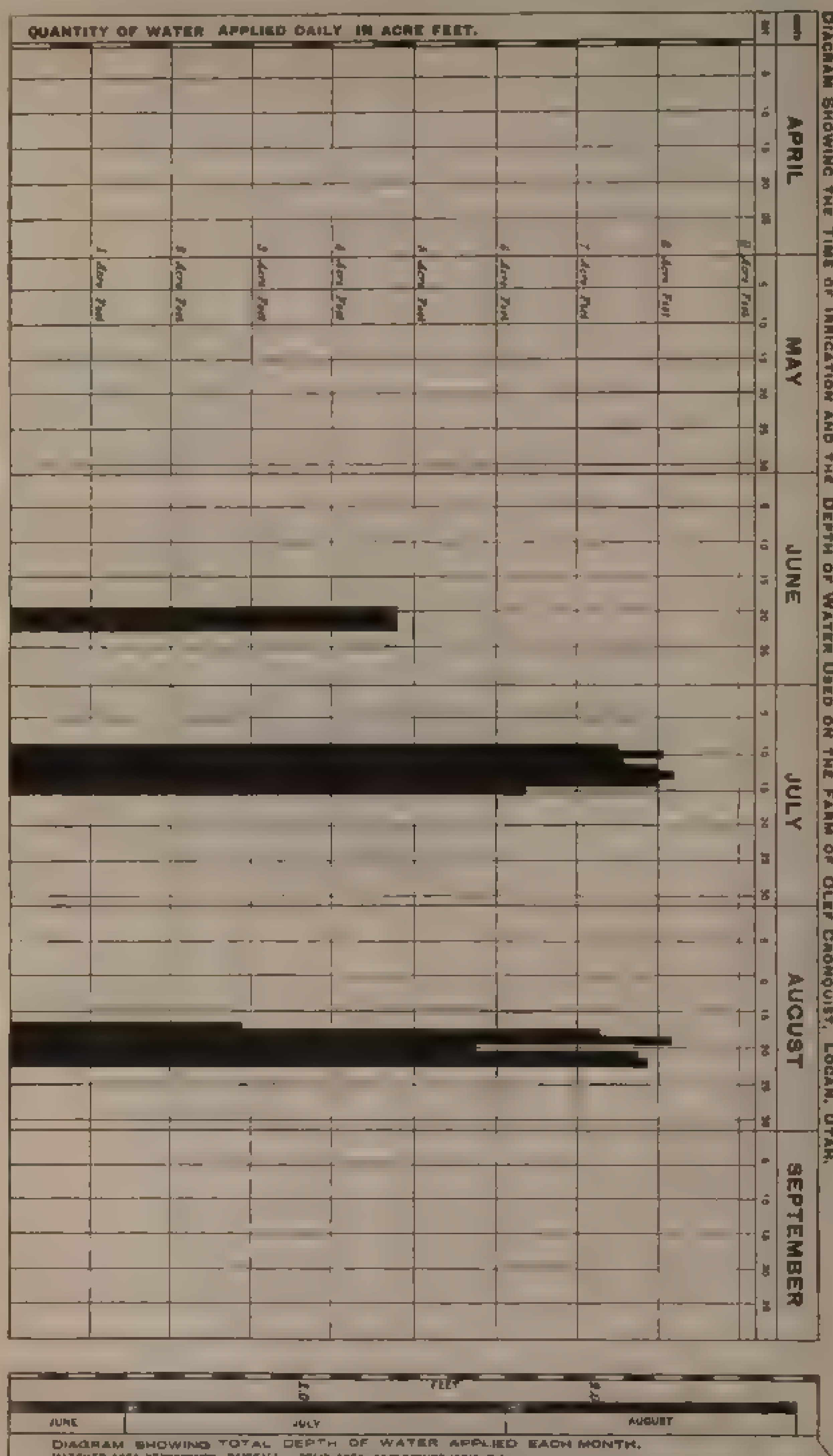


DIAGRAM SHOWING THE USE OF WATER [redacted] FARM [redacted] LOGAN, UTAH.

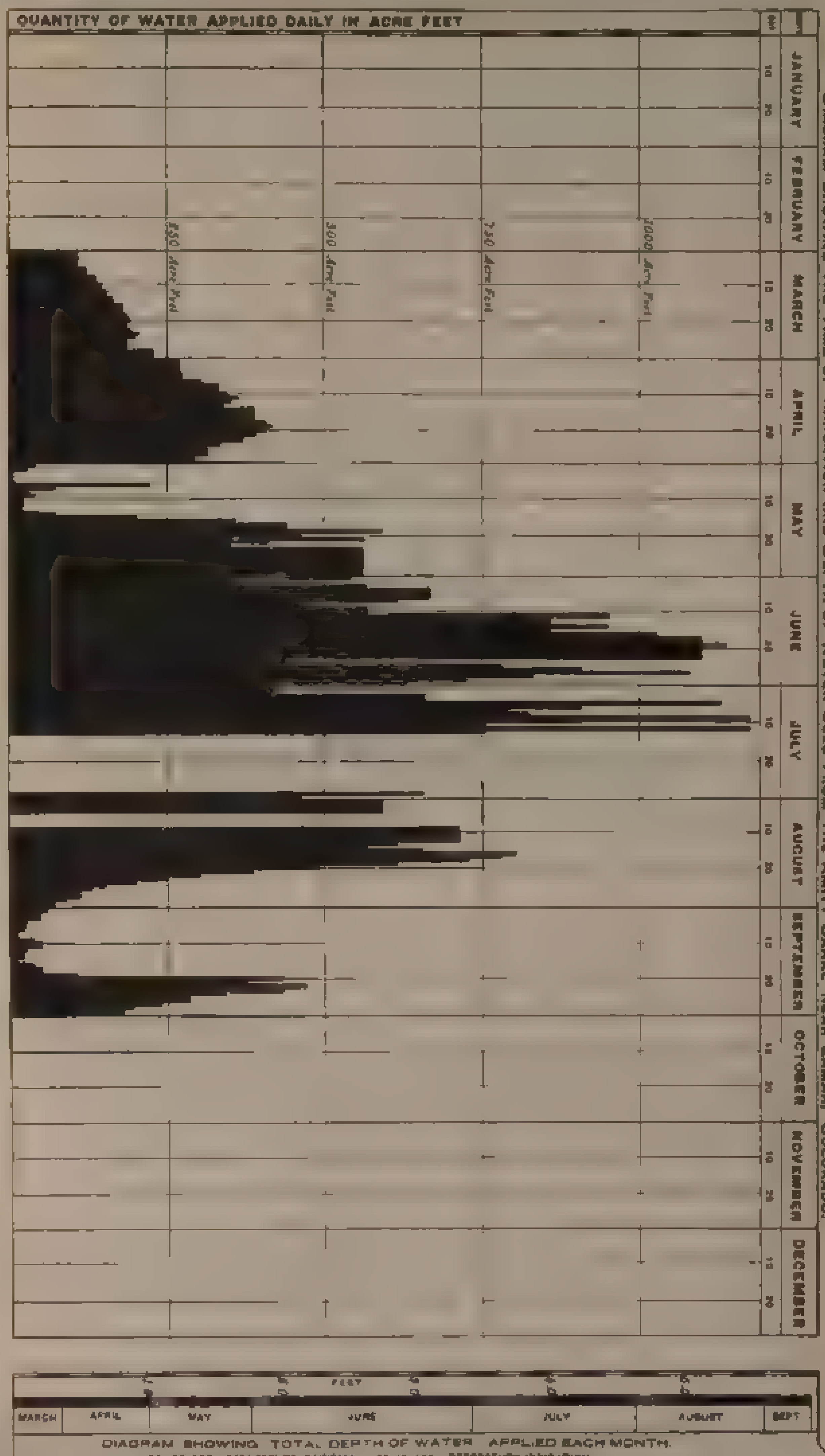


DIAGRAM SHOWING THE USE OF WATER NEAR LAMAR, COLO.

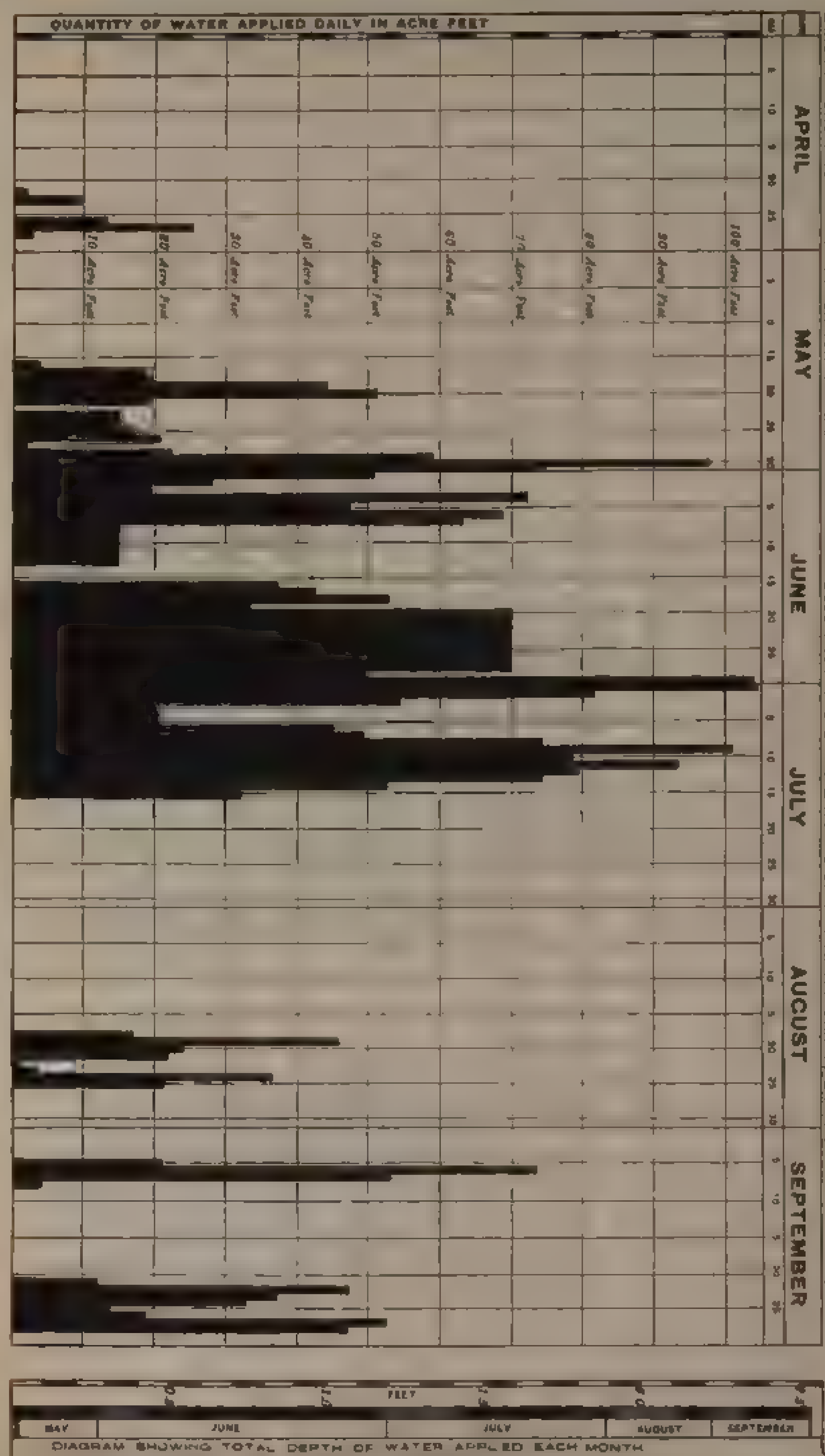


DIAGRAM SHOWING THE USE OF WATER UNDER BILES LATERAL, NEAR LAMAR, COLO.

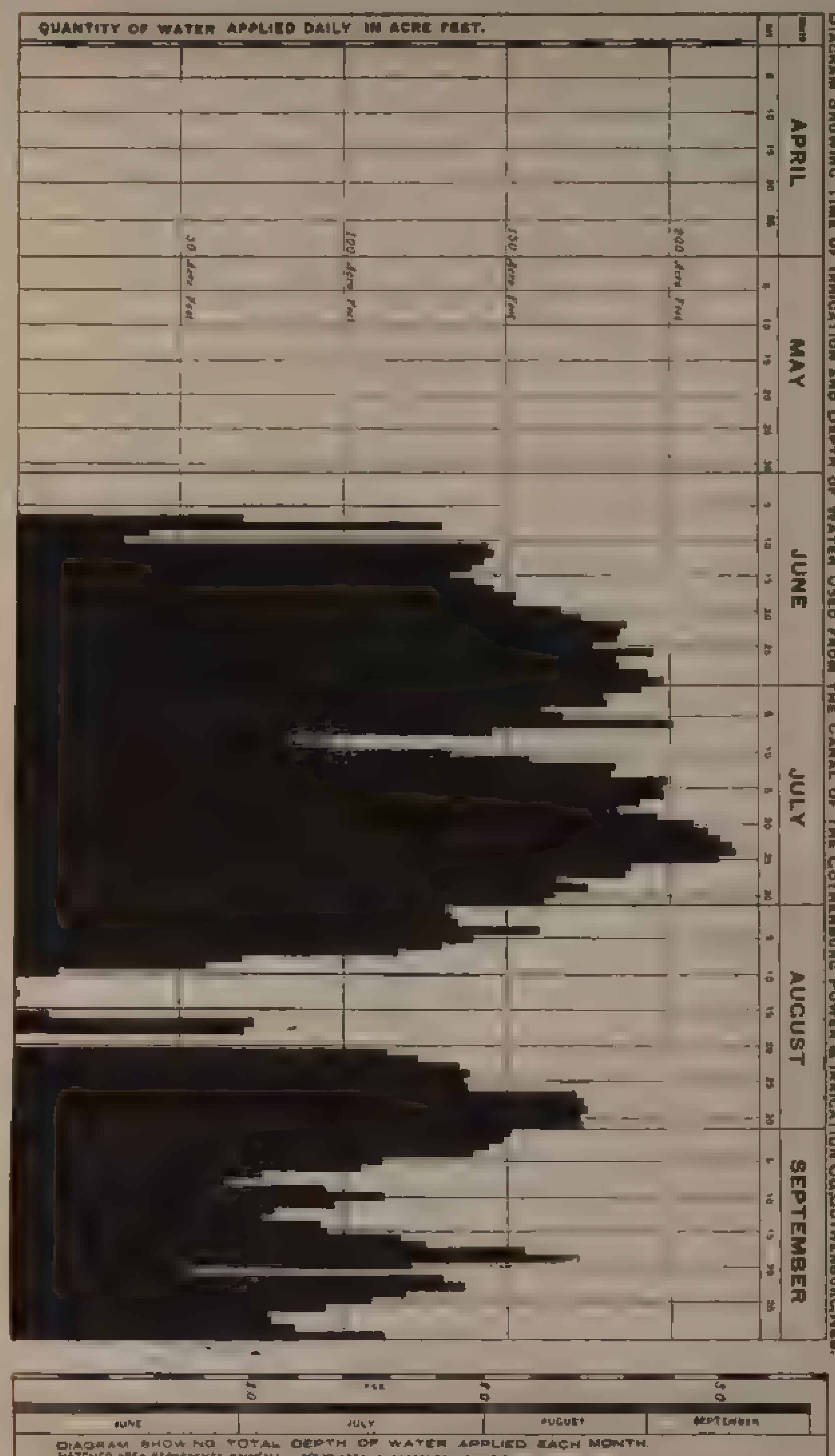
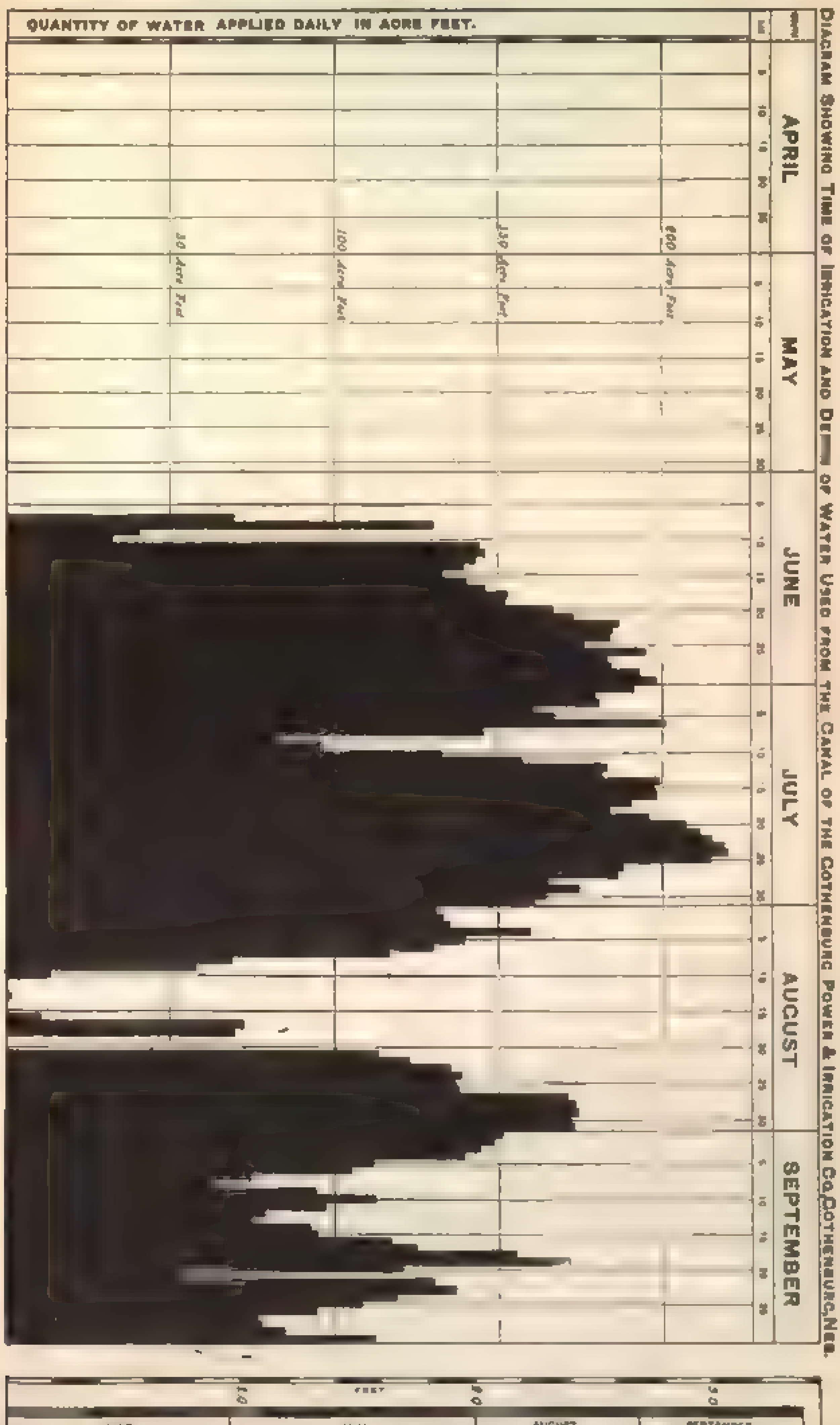


DIAGRAM SHOWING THE USE OF WATER NEAR GOTHENBURG, NEBR.



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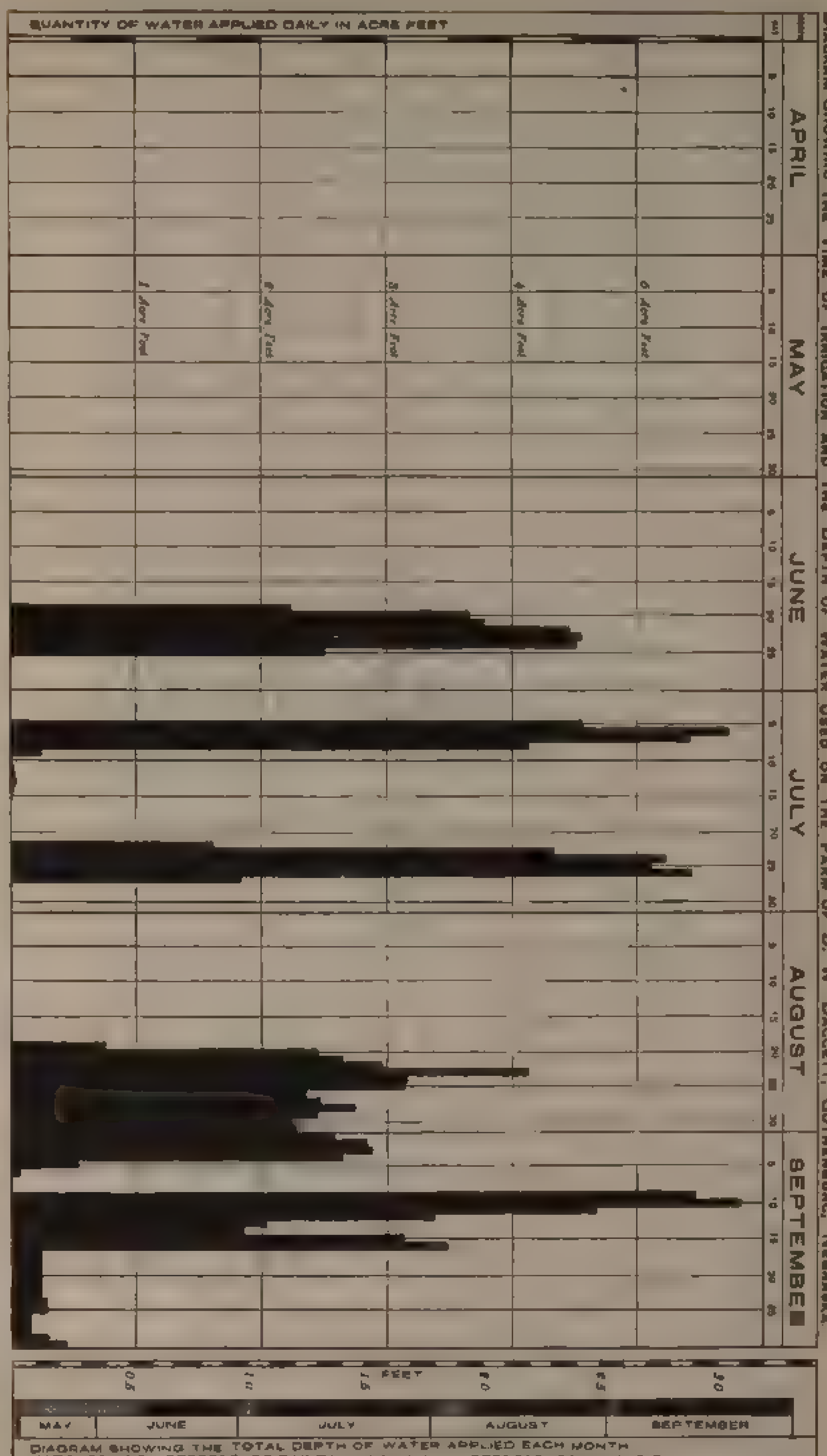


DIAGRAM SHOWING THE USE OF WATER ON DAGGETT'S FARM, NEAR GOTHENBURG, NEBR.

Plate XIX shows how intermittent was the supply furnished the Biles Lateral. This lateral leaves the main canal over 40 miles below the headgate; hence the length of the periods of scanty supply are increased by loss of water through seepage and evaporation. The diversity of crops under the Biles Lateral would require an almost constant volume of water to be provided; yet during a month beginning July 17 no water was used. It is difficult to follow the fluctuations of the discharge of the main canal to the lateral. The supply furnished by the river, the volume used between the headgate and the point of diversion of the lateral, and the extent of loss through seepage and evaporation all served to complicate the diagram.

DIAGRAMS SHOWING USE OF WATER NEAR GOTHENBURG, NEBR.

(PLATES XX AND XXI.)

Two stations were maintained during the season of 1899 on the irrigation system of the Gothenburg Power and Irrigation Company, at Gothenburg, Nebr. One station was installed on the Gothenburg Canal and another on a lateral some 6 miles east of the town of Gothenburg. The effect of the grade given to the Gothenburg Canal is almost totally destroyed by a system of checks along it, put in for the purpose of raising water so that laterals may be taken from the channel. These structures made it impossible to put in measuring flumes or independent weirs. The conditions being suitable, one of the checks was utilized as a rectangular weir.

The irrigation period proper is shown on Plate XX, giving the discharge of the canal, and is included between June 7 and August 10. Water was used later than August 10, but it was not needed for the growth and maturity of crops. The ground was irrigated in some cases after the crops had been harvested, so that the land could be plowed. During the irrigation season the flow of the canal was regulated as the use varied, and but little water ran to waste either at the lower terminus of the canal or through laterals. At Gothenburg is located a reservoir of considerable area, through which the canal runs. This body of water serves to furnish a steady discharge for the canal when such is desired. However, as the demand for water changed each day the volume flowing in the canal varied to meet it, so that the diagram is somewhat irregular in appearance.

The measurements made to determine the duty of water utilized were kept on the farm of D. W. Daggett near Gothenburg. The length of the lateral from the main canal to his land was only a few feet, so that the measuring weir was installed in the bank of the canal. The diagram (Pl. XXI) shows the volume of water used on his farm, and indicates the time when irrigation was necessary and the period required for the same. It will be noticed that water ran in the main canal before any was used for irrigation on the farm. The same fact

would be shown if measurements had been kept on every lateral diverting water from the canal. As is generally true of uncemented canals, the discharge was lost by percolation during the first few days of the season. Only corn and wheat were raised and served by the volume of water shown on the diagram. The times when irrigation was necessary are plainly indicated. No water was needed for these crops after July. The discharge shown for August and September either ran to waste or was used to moisten the ground for plowing.

DIAGRAMS SHOWING USE OF WATER NEAR WHEATLAND, WYO.

(PLATE XXII AND FIGURES 12 AND 13.)

The irrigation system of the Wyoming Development Company is the largest in that State. Two stations were installed under this system during May, 1899; one on Canal No. 2 and another on a lateral taking water from it. Water was turned into the canal on June 11, but little was utilized for irrigation before the 20th. Not only the channel of the main canal, but the entire distribution system had to be saturated. The diagram showing the discharge of water in the main canal indicates that the season began and ended abruptly. It has the appearance of an incomplete record, as though the station had been installed after the use of water began, and that irrigation was continued after the record was concluded. However, such is not the case. The canal is supplied by a reservoir, in addition to diverting water directly from Sybille Creek. The discharge from the reservoir can be varied at will; hence the canal carries the amount of water needed for irrigation under it each day. The crop which requires the greatest volume of water is alfalfa. The steady discharge of the main canal, as shown by the diagram, is largely due to the use of water on areas devoted to this crop. From the 12th of June to the 7th of August the alfalfa was irrigated three times or more.

The land under the lateral was devoted to raising corn and oats. The diagrams showing the volume of water needed for these crops indicate the difference in the irrigation season for the two. As shown by fig. 12, it was necessary to irrigate the oats three times. The rainfall which occurred in June doubtless served as another irrigation. The area of the field was small, hence it was irrigated in from three to five days. Figure 13 shows the time when corn needs water at Wheatland. Irrigation began on July 24 and ended on the 29th.

The rainfall which occurred in September came after all irrigation had ceased and all crops had been harvested; hence it does not in any way affect the volume of water used. Unless the precipitation which occurred in August fell during the early part of the month it had no value as an aid to growing crops.

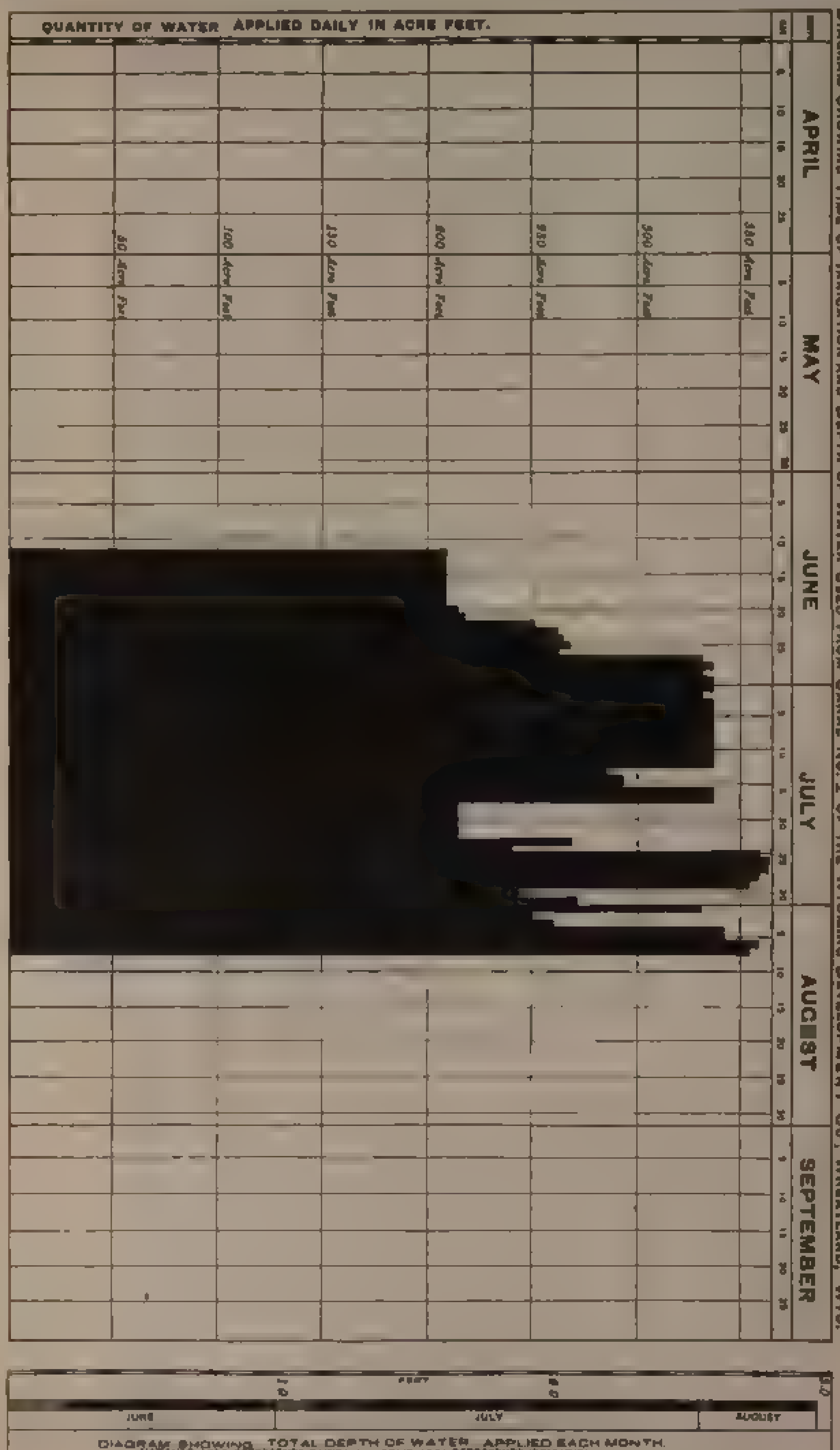


DIAGRAM SHOWING THE USE OF WATER NEAR WHEATLAND, WYO.

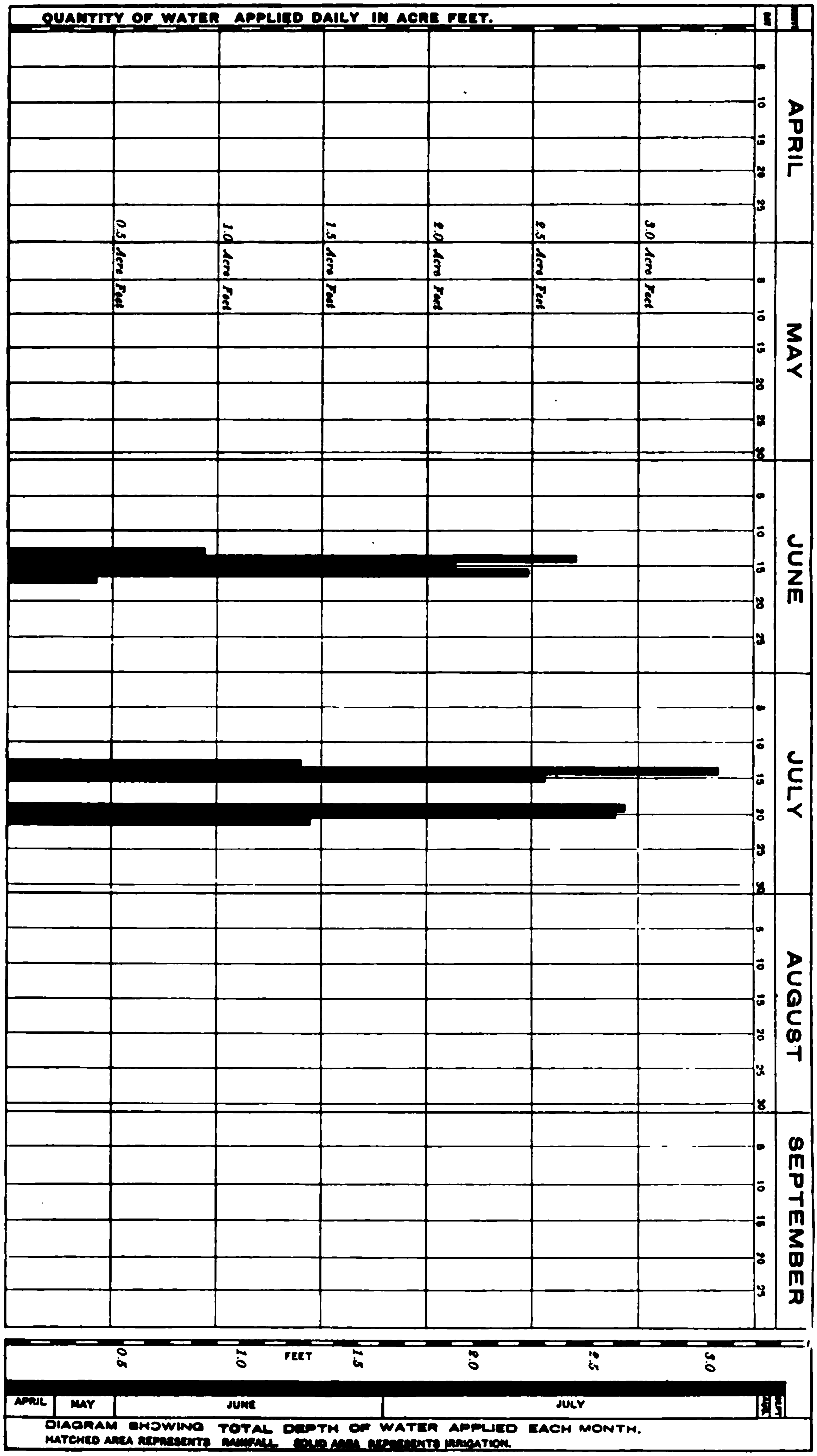


FIG. 12.—Di… on oats at Wheatland, Wyo.

FIG. 13.—Diagram showing the use of water on corn at Wheatland, Wyo.

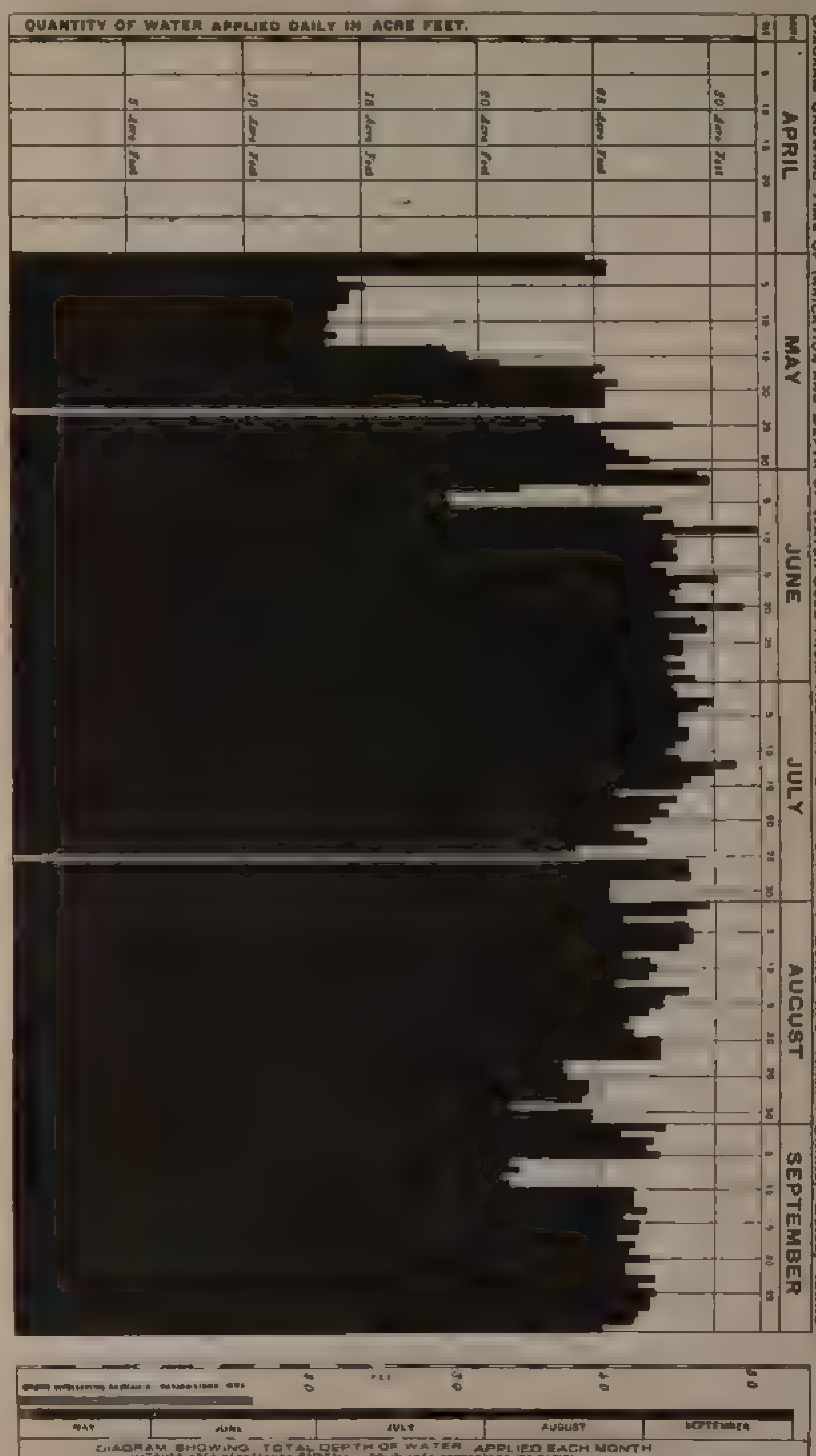
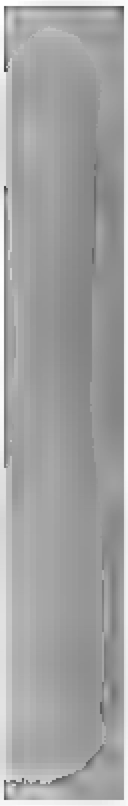
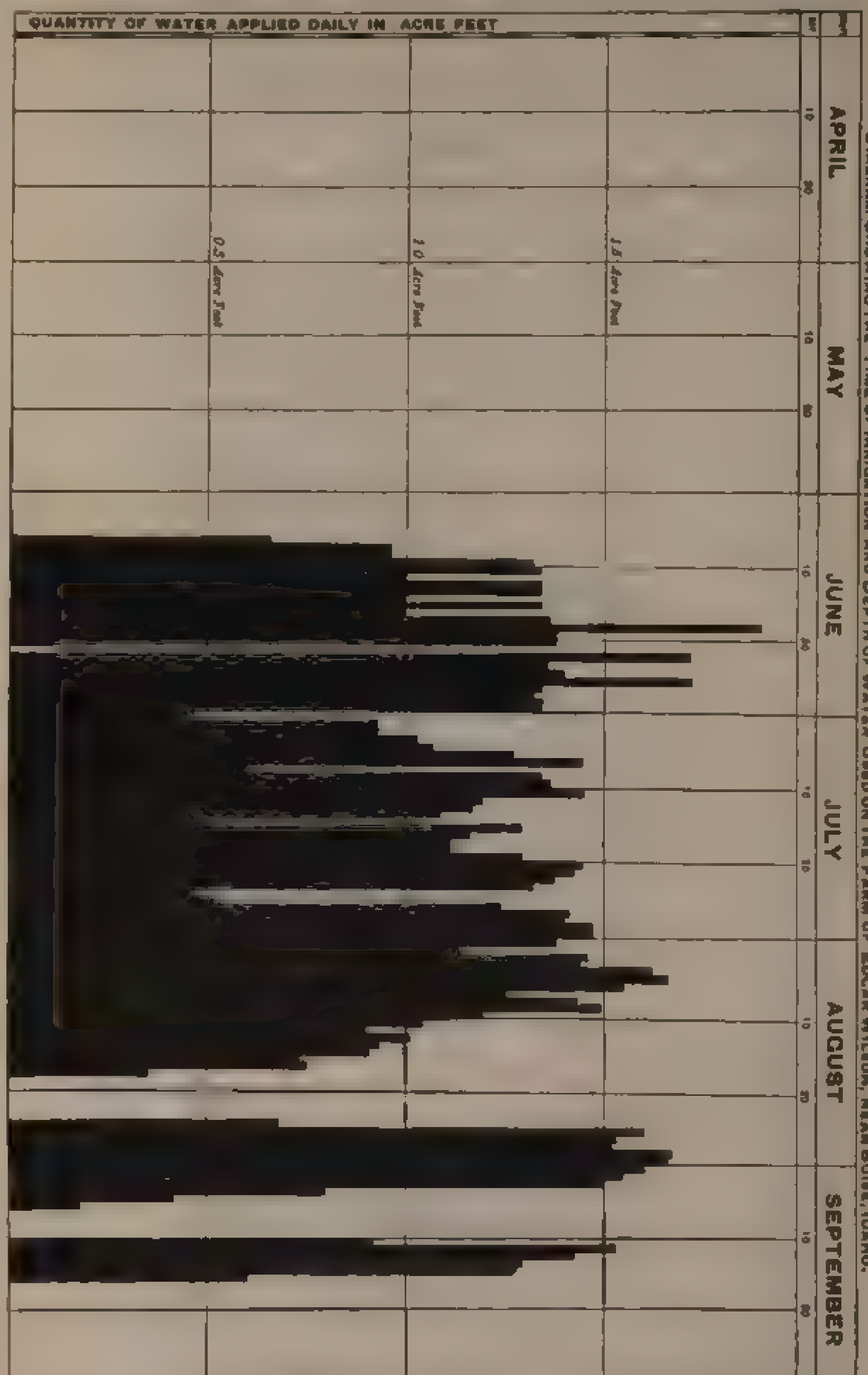


DIAGRAM SHOWING THE USE OF WATER AT BOISE, IDAHO.

[illegible]





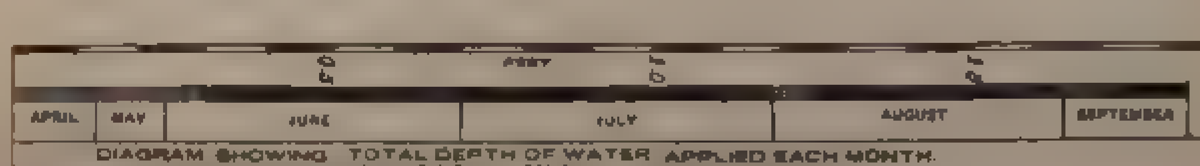


DIAGRAM SHOWING THE USE OF WATER ON ORCHARDS AT BOISE, IDAHO.

[redacted]

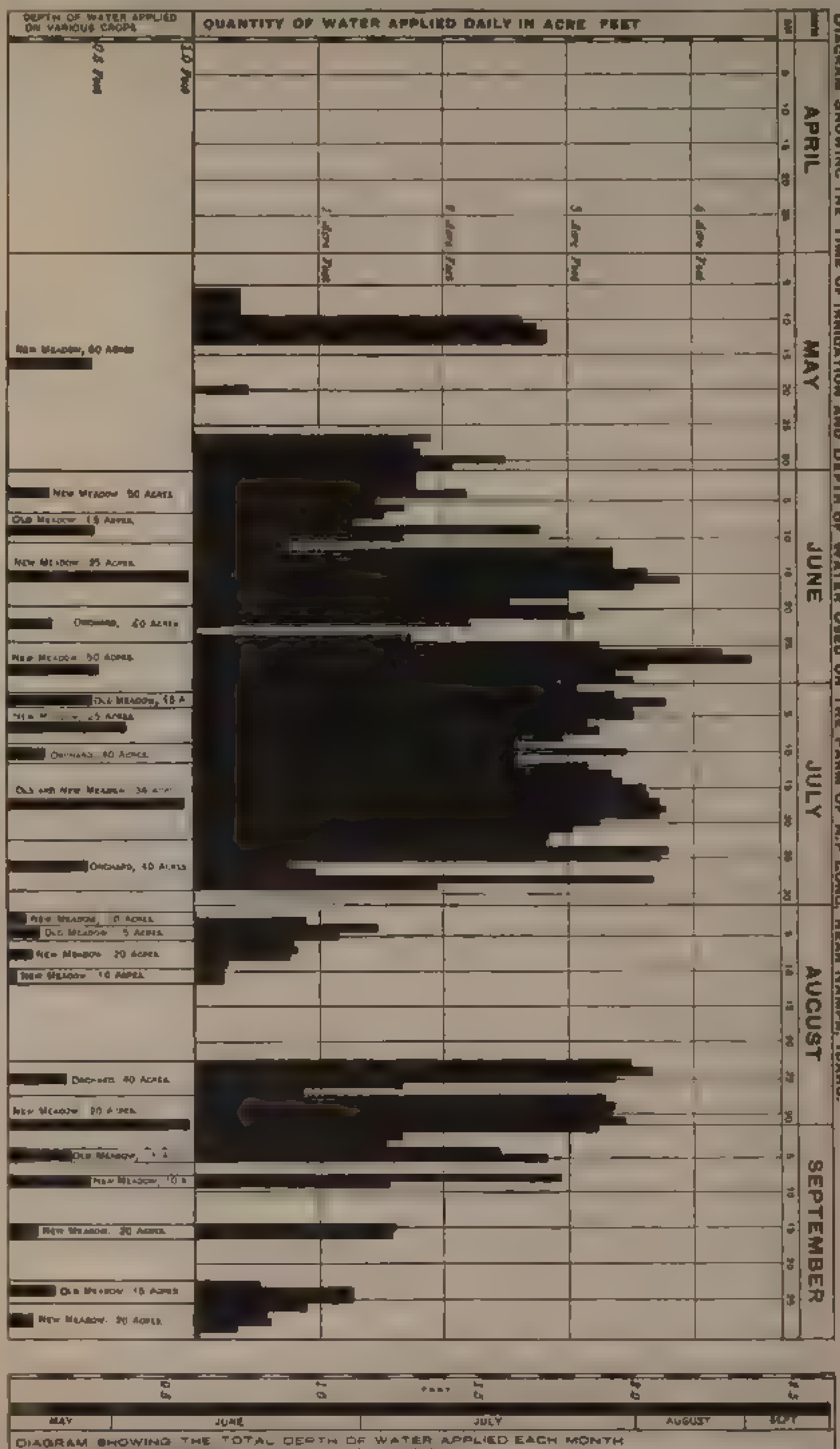


DIAGRAM SHOWING THE USE OF WATER ON A FARM NEAR NAMPA, IDAHO.

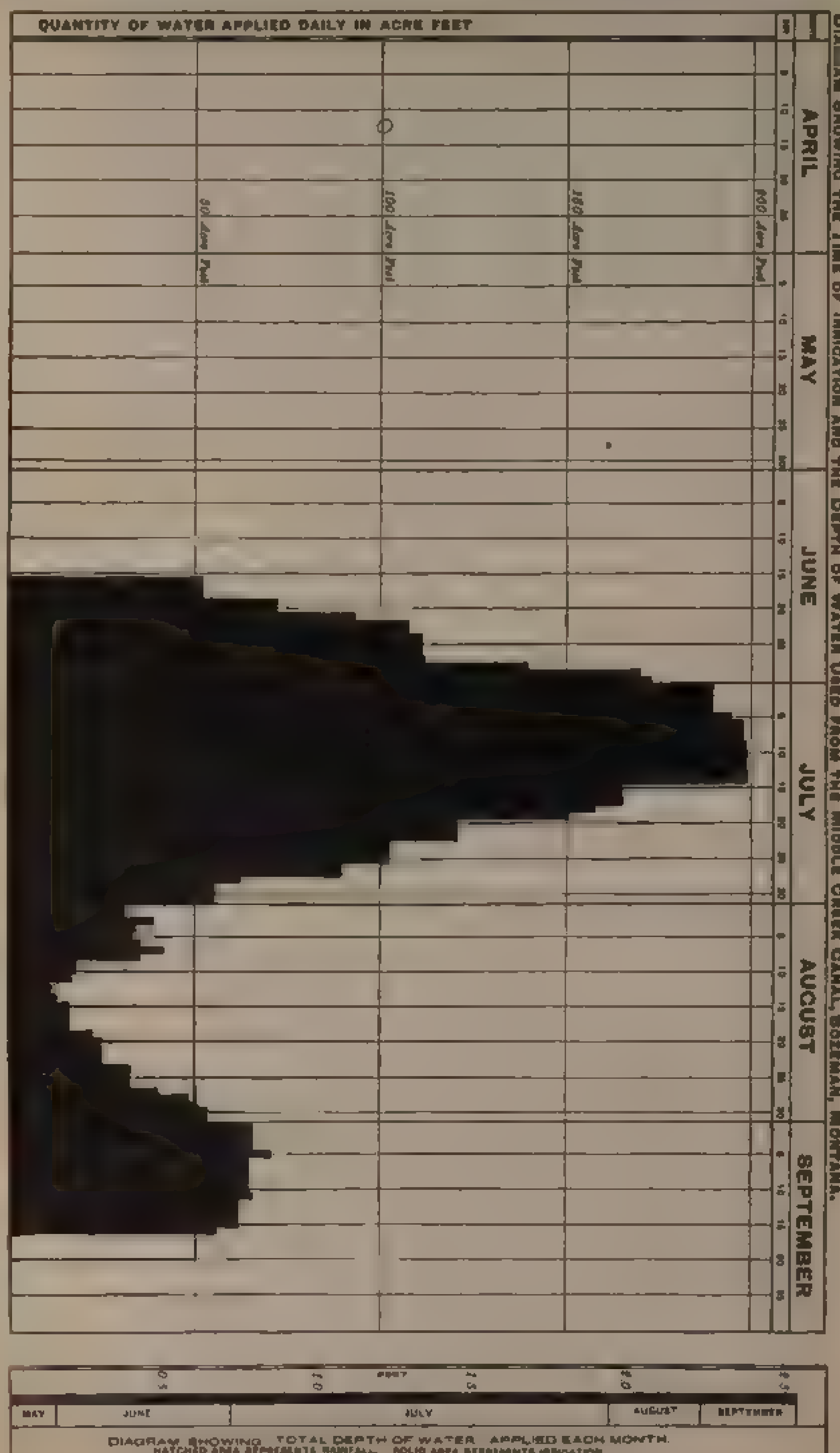


DIAGRAM SHOWING THE USE OF WATER NEAR BOZEMAN, MONT.

DIAGRAMS SHOWING USE OF WATER NEAR BOISE, IDAHO

(PLATES XXIII, XXIV, AND XXV.)

The investigations in Idaho were confined to canals taking water from the Boise River. The entire work deals with the use of water on farms and from laterals. No measurements were made of the water used from canals, but the investigations carried on relative to the use under the Rust Lateral, as shown by Plate XXIII, were quite similar to the record obtained from canals elsewhere. The season begins abruptly, showing that irrigation was practiced by a number of farmers as soon as a supply was afforded. The diagram shows that no great fluctuations took place in the discharge of the lateral. This can be explained in several ways. A large number of users generally have to irrigate a variety of crops. Each man is his own judge as to when to plant and when to irrigate. If in addition the irrigators are inclined to waste water, the volume consumed becomes more uniform.

The diagram (Pl. XXIV) showing the volume of water used for the irrigation of the orchard of Mr. Wilson, near Boise, indicates a much more economical use. From June 7 to August 14, inclusive, irrigation was practiced constantly, but the flow was so regulated that the entire volume of water received by the land, including the rainfall during the irrigation season, would cover it to a depth of only 1.8 feet.

Plate XXV is the most interesting diagram from Idaho. It shows the volume used on the farm of Mr. A. F. Long, near Nampa. Irrigation was begun in May and continued until late in September. The unusual length of the irrigation season is due to a large acreage of meadow. The land devoted to orchards was irrigated during practically the same season as covered by the irrigation of Mr. Wilson's orchard. Both the old and new meadow were irrigated at intervals throughout the season. The third portion of the diagram under the discharge diagram shows the dates when the various crops were irrigated, and the depths to which the land was covered each time. Mr. Wilson's orchards required steady irrigation for over two months. Corn and oats at Wheatland required an irrigation period of six days and eleven days, respectively, while Mr. Long's new meadow was irrigated often during a period of five months, beginning with May. The length of the season for irrigating grains and fruits in the Boise Valley is shown by the records furnished from the farms of Mr. Wilson and Mr. Long. The season practically begins on the 1st of June and ends at about the middle of August. The water used before and after these dates plays no important part in the total volume of water applied to the land.

DIAGRAM SHOWING USE OF WATER NEAR BOZEMAN, MONT.

(PLATE XXVI.)

Plate XXVI shows the results of the measurements of the discharge of the Middle Creek ditch, near Bozeman, Mont. The total discharge of the Middle Creek ditch, as shown by the diagram, was 8,074 acre-feet, or enough including rainfall to cover the land irrigated to a depth of 2.56 feet. The use of water after August 15 is rather unusual, and the irrigation season for Bozeman really lies between the middle of June and that date. The time when irrigation is necessary at Bozeman is practically the same as at Wheatland, Wyo. The diagrams for different places, however, are not similar. The use at Bozeman begins on the 16th and gradually increases until the 1st of July. This gradual increase and decrease in the volume used, while partially due to a short season, can, in a measure, be ascribed to a large area of the irrigated land being sown to grains and garden produce.

REPORTS OF SPECIAL AGENTS AND OBSERVERS.

The stations included in this report fall naturally into two groups, the first including the States and Territories in which the use of water may be continuous; the second those in which it is interrupted during the winter months. The first includes Texas, New Mexico, Arizona, and California; the second, Nebraska, Colorado, Wyoming, Montana, Utah, and Idaho. The reports follow in the order in which these States are here named:

TEXAS.

The distance from the eastern boundary of Texas to its western limit at El Paso is 700 miles. The variation in annual rainfall between the two extremes is 37.6 inches, being 48.7 inches at Texarkana and 11.1 inches at El Paso. Eastern Texas therefore is humid, western Texas is arid, while the north central portion is debatable ground.

In the arid section of the State the use of water in irrigation extends from the Gulf of Mexico to the northern limit, a range of 10 degrees of latitude. In the southern end of this portion of the State irrigation in winter is practical to some extent; in the north it is restricted to the spring and summer months. A comprehensive study of the methods of irrigation in this State is therefore an undertaking of considerable magnitude, and the work done in 1899 was only a beginning.

The observations on the duty of water in 1899 were made at Beeville on the Gulf coast near the southern extremity of the State. This place was chosen because it is in the section between the regions where irrigation is necessary and where it is simply advantageous. In climate and products it is in some respects different from all other stations at which observations were made.

No measurements were made in northwestern Texas because those made at Carlsbad, N. Mex., were regarded as applying fairly well to this region. The measurements in Texas are being made by S. A. McHenry, superintendent of the Beeville substation of the Texas Agricultural Experiment Station. The use of water at this place being continuous, no report can be made at this time of the annual duty. The only crop irrigated during the summer was watermelons. A patch of watermelons was irrigated on June 1 and the water used was equal to a layer 1 inch in depth over the surface irrigated. It was estimated that the yield of the irrigated land was about 25 per cent greater than that of an adjacent patch not irrigated. The summer rainfall this year was ample for most crops, being nearly 12 inches for the six months from May to October.

All the streams of Texas carry more or less sediment in suspension. This fact has delayed the construction of many large irrigation works, and the solution of the problems relative to the effect of silt on ditches and cultivated fields must be brought about before the irrigated area in Texas is greatly increased. When water containing this silt is applied to a field, a deposit is left on the surface. Whether this has been beneficial or otherwise has long been a disputed question. It is at present the most important question connected with irrigation in the Southwestern States. Those most interested in the agricultural interests of those States have asked for a careful study of the problems connected with the depositions of silt in canals and on fields by some disinterested party.

With this end in view, arrangements have been made with Prof. J. C. Nagle, of the Agricultural and Mechanical College at College Station, Texas, for the collection and analysis of samples of water from important streams of Texas. He is to be aided by the chemist of the State experiment station in the analysis of the samples. He has already collected a large number of samples from various streams during floods and during seasons of low water. These have all been forwarded to College Station, where the work of analysis is being carried on. The work of collecting the samples from the rivers has raised problems of its own. A special instrument has been designed and constructed which permits samples to be collected at any depth between the surface and the bed of the stream.

The report on the results of this investigation will be prepared by Professor Nagle and published in bulletin form.

NEW MEXICO.

There are two important irrigation districts in New Mexico: The valleys of the Rio Grande and of the Pecos. Measurements of the duty of water were made in both. The records on the Rio Grande were kept by Profs. Charles A. Keffer and J. D. Tinsley, of the New Mexico Agricultural Experiment Station; those on the Pecos by Mr. W. M. Reed, chief engineer of the Pecos Irrigation and Improvement Company.

The work in this Territory at the experiment station was conducted for the purpose of information rather than for pecuniary profit, and had the further drawback of an insufficient water supply during part of the year. The results were so unsatisfactory that they are not given.

USE OF WATER IN IRRIGATION IN THE PECOS VALLEY.

By Special Agent W. M. Reed,

Chief Engineer of the Pecos Irrigation and Improvement Company.

BEGINNING OF AGRICULTURE IN THE PECOS VALLEY.

Previous to 1888 the Pecos Valley was known only to range stockmen and a few farmers who had settled on the small streams and springs where it was easy to divert water for irrigation purposes. The success of these few farmers demonstrated that the soil, water, and climate of the valley were adapted to successful farming, and this knowledge led Mr. Charles B. Eddy and Mr. Charles W. Greene to attempt reclaiming the valley upon a large scale. Others were interested and companies with strong financial backing were organized to carry out the ideas of Messrs. Eddy and Greene. Work was begun on a canal from the Rio Hondo, 5 miles east of Roswell, and also on a canal from the Pecos River 6 miles north of Eddy. From March, 1889, the work was carried on with vigor until the system was in working order.

As this report is to cover only the investigations in Eddy County, nothing will be said about the canal in Chaves County, taken from the Rio Hondo, more than that it was carried to completion and farming was begun under it in the summer of 1891. At the present time there are about 4,000 acres in cultivation under the system.

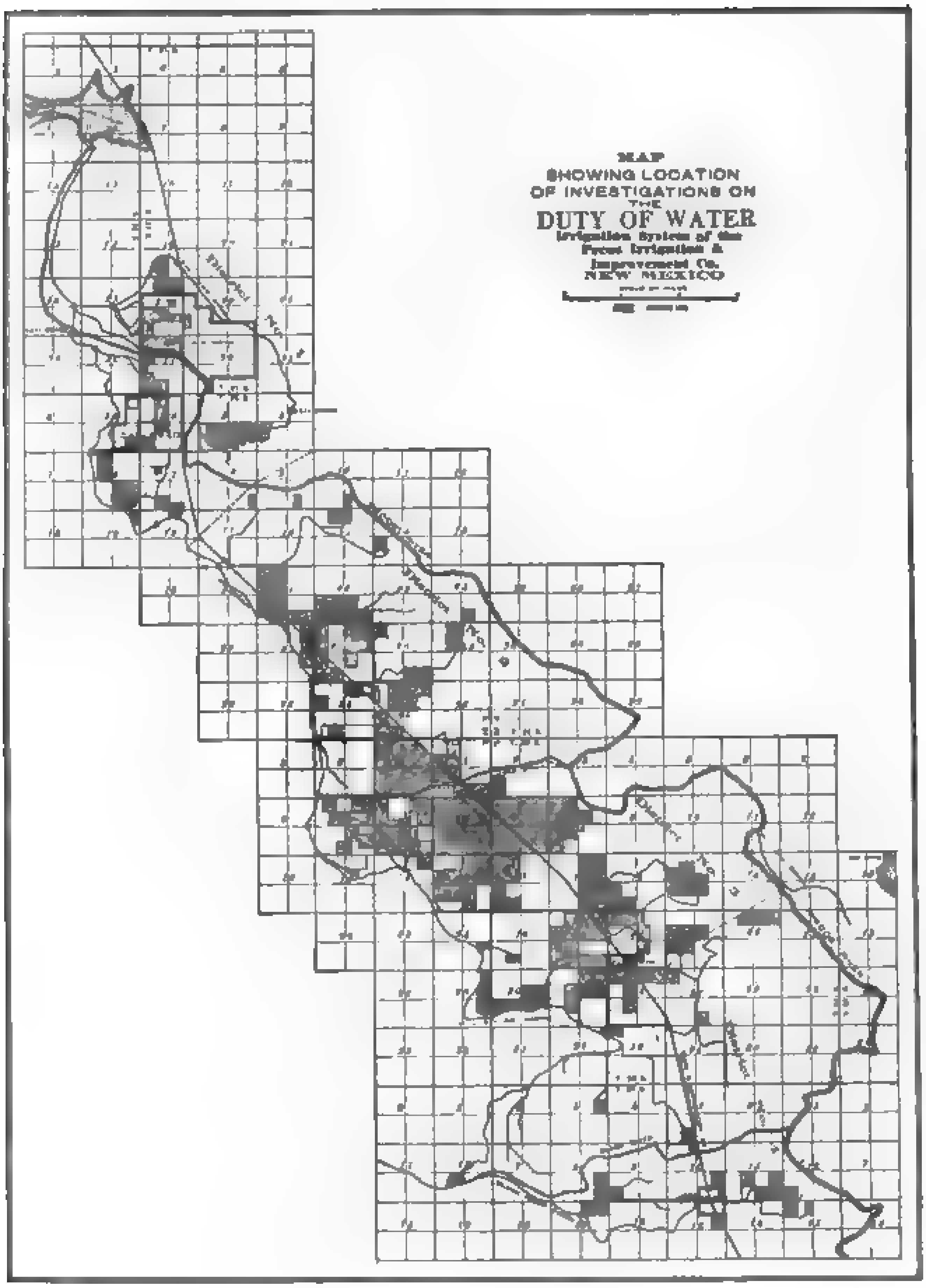
THE IRRIGATION SYSTEM OF THE PECOS IRRIGATION AND IMPROVEMENT COMPANY.

(MAP, PLATE XXVII.)

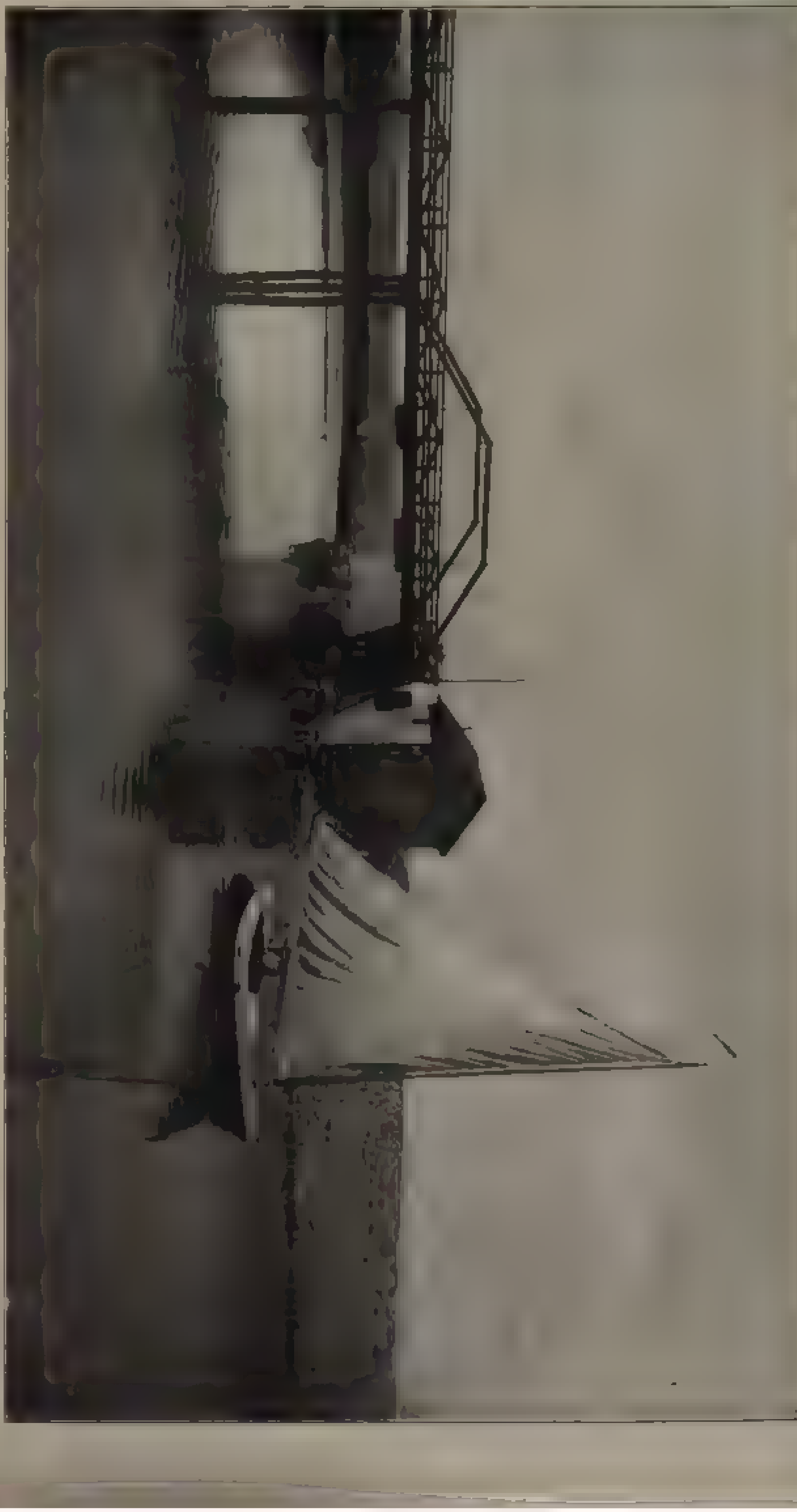
RESERVOIRS.

The total annual flow of the Pecos is sufficient to supply all the water for irrigation that the canals now built will ever be called upon to supply, but the discharge is very irregular. There are floods in midsummer, but often in the spring and early summer months the flow of the river is not sufficient to supply one-half the amount of water required; therefore from the inception of the project storage reservoirs were considered necessary and were provided for in the plans of the system. Several sites were selected and surveys and estimates made, but up to the present time it has been found necessary to construct but two. These are Lake Avalon, known as the distributing reservoir, and Lake McMillan, the storage reservoir (Pl. XXVIII). The general plan of construction is the same in both. In each case the reservoir is formed by a dam directly across the Pecos River. Nature had done much toward making these reservoirs possible. In each case the limestone bluffs approach the river on each side, making it only necessary to connect the two with a strong embankment. In the case of Lake Avalon it required an embankment 1,380 feet in length, maximum height 50 feet; at McMillan an embankment 1,686 feet long, and maximum height 52 feet. In each case the dam is constructed of a wall of loose rock, slopes 1.5 horizontal to 1 vertical on the downstream side and a dry-laid wall on the upstream side, slope one-half horizontal to 1 vertical, with a crown of 6 feet at McMillan and 10 feet at Avalon. In front of this is an apron of earth, crown 14 feet at McMillan and 10 feet at Avalon, and slope 3.5 horizontal to 1 vertical. The earth was laid in layers of about 2 feet in thickness and was kept moistened with pump and hose. On the face of the earth is 18 inches of rock, laid by hand and sledged firmly. That portion of the slope that is under the water all or a part of the time has flattened out and now slopes about 5 horizontal to 1 vertical. The riprap followed the change of slope without a break, and now the dams have reached a point of great stability, and will undoubtedly become stronger each year.

Lake McMillan when full submerges 8,331 acres and has a capacity of 80,000 acre-feet. In order to bring it up to this capacity an embankment 5,200 feet in length, maximum height 18.8 feet, was constructed across a low piece of ground to the west of the main dam. The reservoir is provided with an outlet canal on the east side 2,000 feet in length, cut through the solid rock, and leading back into the river at a point about 300 feet below the dam. The water is regulated through this canal by means of wooden gates raised by iron screws, opening through bulkheads. These gates are six in number, 8 feet high and 4 feet wide, with the openings 3 feet in the clear. A spillway was made between the east end of the dam and outlet canal. The water



MAP OF THE IRRIGATION SYSTEM OF THE PECOS IRRIGATION AND IMPROVEMENT COMPANY, NEW MEXICO.



LAKE McMILLAN RESERVOIR

from this spillway returned to the river bed at a point very close to the slope of the dam. As this was considered a danger to the construction, the spillway was abandoned and blocked. The spillway that is used is an opening about 400 feet wide through the embankment before mentioned, and about 1 mile west of the dam. The water from the spillway follows a shallow arroyo (ravine), and is returned to the river about 2 miles below the dam. The water began cutting back at the discharge end, and has continued toward the reservoir until now it is within 1,100 feet of the reservoir proper. Owing to there being less water in the Pecos, and therefore only two days of spill during the present year, there has been no further erosion in that time. At this point protective works must be installed soon, or the water will cut back into the reservoir and lessen the storage capacity. There is probably little danger here of a great disaster, as the natural slope of the reservoir bottom toward the center is but slight, and more than a mile would have to be cut back before the channel would reach deep water.

Lake Avalon, the distributing reservoir, submerges 1,980 acres, and has a storage capacity of 6,300 acre-feet. The construction of the dam has already been described. There are three spillways from the reservoir proper and one in the canal just below the outlet gates. Spillway No. 1 is situated between the headgate in the canal and the dam proper. There are 31 gates, 5 feet in width, which can be used after the water reaches the height of 12 feet 4 inches on the headgates. The gates to this spillway are on hinges and are secured by a latch when closed. A blow from a hammer will release the latches and allow the gates to open. One man can open all the gates in less than five minutes. The water pours over solid rock ledges and no signs of wearing away are visible. Spillway No. 2 is just beyond the west end of the dam. It is an open cut through solid rock 250 feet in width, and delivers the water back to the river about 600 feet below the dam. The rock is limestone, with occasional streaks of soft material toward the lower end that show some erosion, but it will be many years at the present rate of wear before any protection work will be required. Spillway No. 3 is still farther west one-half mile. It is in the same kind of material, and is 400 feet in width. The water from this spillway follows an arroyo and enters the river at the same point as that from Spillway No. 2.

Spillway No. 1, and 100 feet of No. 2, were constructed at the same time as the dam in 1889. These proved insufficient for the floods of 1893, when the estimated flow of the Pecos was 41,000 cubic feet per second, and the dam was destroyed. The reconstruction of the dam was immediately undertaken, and the additional spillway was constructed at this time. Since that time no trouble has been experienced in passing the flood waters.

The spillway in the main southern canal is below the headgates

about 200 feet. It is a masonry wall, set on solid rock, with top of wall just below the level of the canal grade. On the top of the wall it is arranged for slash boards. When the slash boards are out a stream of water 70 feet in width and 4 feet in depth can be returned over the spillway directly into the river. This spillway is a precaution against damage from waters coming down some small arroyos near the head of the canal, but can be used in connection with the headgates of the canal in passing flood waters of the river.

CANALS.

The canal when it first leaves the reservoir has a bottom width of [illegible] feet, a side slope of 1 vertical to 1.5 horizontal, with a berm of [illegible] feet between excavation and embankment and 8 feet between grade line and top of embankment. The canal has a fall of 18 inches to 5,000 feet. It has but one bank, the upper side being left open for the avowed purpose of receiving storm waters without damage to the embankments. Open spillways are put in the lower embankment at intervals, for the purpose of disposing of the surplus water. Experience has taught that the single bank is not best adapted to the soil and climate. Remarks upon seepage and evaporation will appear later in this report, in explanation of the above statement.

The canal divides at 3 miles, one branch continuing on the east side of the river and watering the suburban property, La Huerta and Hagerman Heights. This branch has a bottom width of 20 feet. The other branch, 25 feet in width, crosses the river and serves the west side, watering the greater part of the land now under cultivation. The river is crossed by means of a wooden flume 528 feet in length and 25 feet wide in the clear (Pl. XXIX). This flume has been a source of much trouble. It has broken three times and caused a large expenditure of money as well as damage to growing crops. Its construction is simply a wooden trough carried on framed bents. The river bottom is solid rock and the bent sills are bolted to the rock. At the ends of the flume the bents now rest on piles, but up to a year ago they rested on mudsills with small cross pieces for additional support, and as the bank is almost pure sand at both approaches there was always trouble. Both floor and sides of the flume are double, but as there is no means of adjusting for expansion or shrinkage, leaks are frequent and numerous, and much calking is needed. The action of water upon iron is so great that nails become useless and renailing of the flooring and the sides below the water level is necessary about once in two years. The flume was built ten years ago and has since been nearly all replaced, a portion at a time.

From the flume to Dark Canyon, about 3 miles, the material through which the canal passes is sandy loam and lime rock. There is some loss here due to seepage, indicated by additional water in some of the springs along the river and by saturated land in the west part.

FIG. 1.—FLUME ACROSS PECOS RIVER.

FIG. 2.—STACKING ALFALFA.

of the town of Carlsbad. The bottom of Dark Canyon where the canal crosses is a mass of coarse gravel and round bowlders. The crossing is made by an embankment on the lower side of the canal line provided with timber spillways so arranged that the flood waters of the canyon will pass over without damage. A bulkhead in the canal at the lower side of the canyon prevents the floods from overloading the canal below this point. There is considerable loss at this point. A large area is submerged by the backwater of the canal, and much water finds its way under the embankment through the gravel. At times, when the canal is carrying the most water, as much as 5 cubic feet per second is flowing on the surface in the canyon below the crossing, and undoubtedly a much larger quantity is flowing through the gravel.

From Dark Canyon for a distance of about 20 miles the soil through which the canal passes is mostly clay loam, and no large amount of water is lost by seepage. At the end of this distance for a mile the material is mostly gypsum, and the loss is enormous, ranging from 20 to 75 per cent of the water flowing in the canal in this distance of 1 mile. Much labor and expense have been incurred in various ways for overcoming this difficulty. Sheet piling, refilling trenches, and lining portions of the canal with good material have given only temporary relief. The most economical way of overcoming this difficulty would be to change the location of the canal. This would throw out some land now subject to irrigation, but it would be much better to do this than to give poor service to all lands below this point.

Three miles below this place the canal crosses Black River, and previous to this year the crossing was made by means of a flume of similar construction to the one crossing the Pecos. During the season of 1898 this flume gave trouble, and it was evident that it had about served its usefulness. The bents rested on mudsills, and the heavy leakage through the decaying timber and joints made a disaster probable at any time. To avoid this difficulty a low masonry dam, length 70 feet, height 4 feet, was constructed one-half mile farther down the stream, and from this dam a new canal 3 miles in length was constructed, intercepting the already constructed laterals. The water is now dropped into the river at the point where the flume formerly crossed and is again taken out at the dam by the new canal. By this means 9 cubic feet per second of water are obtained from the Black River during the irrigating season. The remainder of the flow of Black River is appropriated by private parties farther upstream. By the abandoning of the flume some land was thrown out of the irrigation district, but this seems economical when taking into consideration the better service rendered to the other lands. While the canal was built for some 10 miles south of Black River, it has never been used for irrigation purposes and might as well be abandoned for several years to come, there being plenty of land north of Black River to make a most prosperous section when all is in cultivation.

In the earlier days the management, without consultation with the engineer, sold water rights on land that was too high to be irrigated from the canal as planned and constructed. To deliver water to this land checks were placed in the canal, often 3 feet in height and at intervals so close that the canal, instead of having a uniform grade, is for miles a series of planes with perpendicular drops at distances varying from 1 to 2 miles. This has proved to be a great nuisance. It has constantly maintained the water at a high level, even if a small amount of water only is needed. Necessarily, with the single bank, a large area was exposed to evaporation and seepage. The current is reduced to a minimum, and the aquatic growth, which flourishes so luxuriantly in still, clear water, here becomes a great source of trouble, necessitating considerable expense in removing it, often twice during the irrigating season. It reduces the carrying capacity of the canal at least 75 per cent, and thus when the demand for water was greatest it was almost impossible to get the required amount of water through the canal to the consumers. Arrangements have now been made upon a satisfactory basis with the owners of this high land to abandon the use of water upon it, and the checks will be removed during this coming winter. When these checks are removed and the location of the canal changed so as to avoid the gypsum, the operation of the canal will be much more satisfactory.

LATERALS.

The topography of the country is such that the majority of the main laterals are run on section or subdivision lines, taking the natural slope of the surface as their grade lines. In a few instances drops of either lumber or rock have been put in to prevent erosion where the grade was too heavy. A few laterals with supported grade have been run, using a fall of from 2 to 5 feet per mile. In nearly all cases the flow through the laterals is satisfactory.

THE SALE AND DISTRIBUTION OF WATER TO IRRIGATORS.

Before entering on a history of the measurements of water used it is necessary to describe the terms and conditions under which the canal company supplies it to farmers. There are several forms of contract in use depending on whether the water right is paid for in cash or in a series of payments. Only the essential features taken from a copy of the cash form are given:

Deed and contract No.——

This indenture and agreement witnesseth that the first party has bargained, sold, assigned, granted, and conveyed, and hereby does bargain, sell, assign, grant, and convey, unto the said second party, as a member of the "irrigation" class of consumers under said first party's water rights in said canal as hereinafter limited and defined, to be used in accordance with and subject to the conditions, limitations, rules, and regulations hereinafter laid down and to be hereafter established.

The said water rights are and each one thereof is hereby applied and attached to, *and is* to be used in connection with, the certain tract or parcel of land the description

of which is set opposite the number of such water right, as follows, to wit: * * * all of which real estate is situate in the county of ——, Territory of New Mexico; the intention of the above conveyance being that each of said water rights shall be and remain a right to receive and use during each year, from said canal upon the land named in connection therewith, the amount of water hereinafter specified, and that each of said water rights shall be and remain, so long as the conditions herein reserved are complied with, a right incident and appurtenant to said land so named in connection therewith, and that the whole of each water right shall always remain attached to the whole of said land mentioned in connection therewith and not be divisible so as to convey any right as against the first party to a part purchaser thereof.

Provided, however, and this grant and contract is made upon the express condition and agreement, That the said second party, or the legal representatives thereof, shall and will (in event the same now remains undone) truly and in good faith, comply with all laws and regulations of the United States governing the entry and lawful acquirement of all said land above described, and duly make and perfect final proof of said compliance and acquire full right thereto; and it is herein and hereby expressly reserved by the first party, that in case the foregoing condition and agreement with reference to a compliance with said United States laws and regulations be broken by the second party, or legal representative, then this deed shall become null and void, and all the rights, title, and claim of the second party in and to the water rights hereby conveyed shall revert to the first party, its successors or assigns: *And provided, also*, That no assignment, conveyance, or sale of said water rights, or either thereof, or any part of any such right, or any part of any tract covered by any such right, except in connection with the sale and transfer of the whole of the real estate to which said particular water right applies, shall convey any separate right to the purchaser thereof as against the first party, and that no assignment, conveyance, or sale of the whole of any tract of land covered by a water right shall convey any right to receive and use water therefrom, or be binding hereunder against the first party, until the same shall have been executed in writing, and duly acknowledged and presented for inspection to the first party, at its office at ——, New Mexico, and all amounts due thereupon, hereunder, be paid.

And the first party hereby contracts and agrees, to and with the second party, that it will permanently maintain the said canal and the flow of water therethrough, and that it has not sold, and will not sell, water rights in the same in excess of the carrying capacity thereof.

The amount of water which the first party shall deliver and the second party shall be entitled to receive under each of said water rights is, and shall be, 43,560 cubic feet per annum for each acre of land covered thereby, to be delivered at such times and in such quantities as may be necessary for the production of good average crops, as near the times required by the second party as the first party may reasonably be able, after notice of the requirement as to time and amount of delivery having been given the first party a reasonable length of time in advance, or so much of said amount of water per acre as may be necessary for the production of good average crops, under skillful irrigation, said water to be measured by the method prescribed by the first party; and the right to receive said water being, in addition to the conditions hereinbefore mentioned, under and subject to the following conditions and agreements:

(1) That the second party, and the heirs, assigns, and successors thereof in the ownership of said land, shall pay to the first party, for each year, as compensation for the furnishing of water for irrigating purposes above mentioned, the sum of —— dollars for each acre of the above-described land embraced in a water right, said amount to be paid at the office of the first party at ——, New Mexico, in two equal payments, one-half on or before the 1st day of June and one-half on or before the 1st day of December subsequent thereto, in this and each succeeding year, in advance.

(2) Said water shall be used only to irrigate the lands above described and for domestic purposes, and stock kept thereon, and under no circumstances shall the same, or any part thereof, be used for mining, milling, or mechanical power, or any other purpose not directly connected with, or incidental to, the purposes first herein mentioned.

(3) The first party shall not be required to furnish a greater amount of water limited to each water right above stated than may be reasonably necessary for the production of good average crops under skillful irrigation and cultivation, and the other uses above allowed.

(4) The second party shall not permit said water to be furnished as aforesaid to run to waste, but as soon as a sufficient quantity shall have been used, for the time being, for the purposes herein allowed, shall, in such manner as the first party may prescribe, notify said first party that the said water may be shut off.

(5) The said water shall be delivered by the first party into a lateral ditch or subsidiary canal provided by the second party and connected with the said main canal, or with a lateral or subsidiary canal of the first party; and the manner of delivering, measuring, and regulating the supply of water to the second party shall be prescribed by the first party and at all times under its control; and if the second party shall in any manner change, open, or shut any measuring box, or by any means increase or diminish the aperture thereof, without the consent of the first party; or, in case the second party shall use a supply of water for any other lands, or shall allow any person to use it, except for the purposes herein allowed, upon the above-described premises, or shall in any way whatever take water from any ditch, canal, lateral, or sublateral supplied with water by the first party, except as delivered by the first party, then the second party shall, at the option of the board of directors of the first party, forfeit all right to receive water from the first party for the then current year, and also all moneys paid as compensation for furnishing water for said year.

(6) It is further agreed that if, by reason of any cause, the supply of water shall be insufficient to fill and flow through said main canal according to its estimated capacity, or insufficient to furnish the amount which all the consumers may be entitled to, then the first party shall have the right to distribute such water as may flow through said canal, pro rata, to all persons entitled thereto, and for the purpose of so doing may establish and enforce such rules and regulations as it may deem necessary or expedient; but in case of such pro rata distribution credit shall be given the owner or owners of the water rights hereby granted at a proportionate rate of annual water rental for the amount of water less than 43,560 cubic feet per acre which may have been needed and required by the owner of such water right for purposes herein recognized, but which the first party, on account of such pro rata distribution, may not have furnished; which credit shall be given upon the amount due as compensation for furnishing water to the party who is the owner of the water right upon which the credit is due, at the next semiannual period for the payment of said compensation. And the first party shall have the right to turn the water out of said main canal, and shut the water out of the lateral and service ditches, at any time for the purpose of cleaning or repairing said main canal, its dam or reservoir, or for repairing or putting in new or other wasteweirs, headgates, wastegates, service gates, bridges, or any of the appurtenances of said canal, and during the time occupied thereby the right of the second party to demand and receive water hereunder shall be suspended.

(7) It is hereby distinctly understood and agreed by and between the parties hereto that in case the canals of said first party through which the water rights herein granted are furnished water shall be unable to carry and distribute a volume of water equal to their estimated capacity, either from casual, unforeseen, or unavoidable accident, or the act of God, or if the volume of water proves insufficient from *drought*, or from any other cause beyond the control of said first party, the first party

shall not be liable in any way for the shortness or insufficiency of supply occasioned by any of said causes.

(8) And the second party agrees, in consideration aforesaid, to waive, and hereby does waive, any and all claims for loss or damage by reason of any leakage, seepage, or overflow from any canal or ditches, or from any reservoirs, lakes, or laterals of the first party, either upon the land aforesaid or any other tract belonging to said party, anything in any statute, law, or custom to the contrary notwithstanding.

(9) The second party shall construct and maintain in good order and repair a ditch upon said land, of such size and grade and at such point and location as shall be prescribed by the first party, to catch and conduct to some main lateral ditch of the first party all waste water flowing upon said tract of land.

The regular field force of this system during the irrigating season consists of a watchman at each reservoir, whose duty it is to keep records of the height of water in the reservoir, the amount discharged through the canals and spillways, note condition of the works and keep everything in order, and regulate the flow into the canal as directed from the engineer's office; and four ditch riders, each in charge of a certain portion of the main canal and the laterals from it. Their duties are to deliver the water to the consumers and keep a record of all such deliveries. For this purpose they are provided with a book of slips, two to the page, one detachable. At the end of each delivery the two slips are filled out in duplicate, one detached and sent to the engineer's office, the other remaining as a stub in the book and sent in when the book is filled. The following is a copy of this slip:

Pecos Irrigation and Improvement Company.

Department of chief engineer. Record of water delivery.

Division No., ——, ———. Name of owner, ———, ———. Water right No., ——. Weir, ——. Width, ——. Depth, ——. Date, ——, from ——, —. m. to ——, —. m. Time in hours, ——. Acres irrigated, ——. Variety of crops, ———. Method of irrigation, ———. Nature of soil, ———. Condition of owner's laterals, ———. Remarks, ———. Total, acre-feet, ———.

The measurements are made over weirs, and are not absolutely accurate, as at present there are no automatic registers for determining the head. But as the whole system is connected by telephone, and all water is drawn from or returned to the canal under instructions from the engineer's office, the heads can be kept very uniform, except the variation due to evaporation, and as the measurements are taken twice daily, the results are at least approximate, and will certainly be of great aid in determining the duty of water.

This is the third season that any attempt has been made here to determine the amount of water actually used, and while it is known that the results are not absolutely accurate they give a comparative record, and, when the necessity of selling water by measurement becomes as apparent to both the seller and the consumer as it is to many engineers, methods of accurate measurement will be adopted, although involving considerable expense.

INVESTIGATIONS IN 1899.

The tabulated results of the season's work up to October 1 are divided into four parts, each representing a division, as shown on the map (Pl. XXVII, p. 86). These divisions vary much as to soil, subsoil, etc.

DIVISION NO. 1.

The soil of division No. 1 is nearly all pure sand. The only natural growth before irrigation was mesquite and cat claw—no grass or weeds. The soil varies in depth, but in nearly all instances has a porous subsoil, and while this division has had the most water per acre of the whole system, there is hardly a sign of water-logged land in it. For the division the average duty is about 6.5 acre-feet per acre. Such an amount with heavier land and less natural drainage would create a marsh. That this quantity of water is not needed can be easily understood from this year's record, for those who have used the least water have obtained equally as good crops as others who have used enormous quantities. A great drawback to the economical use of water in this division is the large number of users who farm more as a pastime than as a means of making a living. For instance, sixteen of those whose names are on the list as users have other business besides farming, and give no study to the matter. Every time the surface looks a little dry they demand water, never thinking that perhaps cultivation would do more good. Thus the water is wasted and the land injured, and such will continue to be the case until everyone pays for every drop of water he gets. In this way the waste of water, land, and labor can be curtailed.

The crop yield is much less than in the other divisions. This is partially due to the soil, but more to the bad farming, which includes lack of careful cultivation and a reckless, wasteful handling of the water. A special instance is that of the farm on which one of the Department registers was used. The owner does not farm. It is a beautiful place; thousands of trees grow along the ditches and drives. Water running in the ditches adds beauty to the scene; therefore water is always in them. The cultivation is mostly done by Mexicans and after Mexican fashion. The land is leased to them, so they are their own bosses. Cultivation is generally omitted, and pouring on large amounts of water substituted. It is also thought by those in charge that trees must have a constant stream of water at their roots, yet there are several trees living, probably not growing rapidly, not far from this land, on the same kind of soil, which have not been irrigated in two years. A large portion of the water used on this place during the season just past can be charged to maintenance of beautiful drives and the Mexican style of farming. This farm consists of 80 acres, and during the past season was planted as follows. Alfalfa, 40 acres; corn, 15 acres; orchard, 20 acres; trees, 5 acres. T[illegible] [illegible]tity [illegible]

used on this land in March and April, previous to putting in the register, was, in March, 62.45 acre-feet; in April, 168 acre-feet. The daily use of water from May 3 to November 15 is given in the following table:

Water used on farm of J. J. Hagerman, near Carlsbad, N. Mex., May 3 to October 31, 1899.

[See diagram (Pl. V).]

Day.	May.	June.	July.	August.	September.	October.	November.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		6.0115	5.4131	7.4464	4.2258	4.6104	5.8087
2		4.1714	4.8351	7.7522	4.1712	4.2804	.4793
3	6.4757	3.3408	4.1714	8.1080		5.1651	
4	7.0124	3.5266	5.0636	7.6754		5.2956	.2706
5	6.7573	7.7958	4.3700	6.3846		5.0640	7.0539
6	6.5056	7.5316	3.6104	5.8306		5.3766	6.6102
7	5.8150	7.5316	2.3324	5.7298		6.3305	6.6102
8	6.0115	7.0124	4.7650	5.5712		6.7578	6.5052
9	5.0636	6.7573	.5795	5.3740		6.1616	6.1364
10	4.3890	5.8905		6.0936	3.1092	2.7755	5.1412
11	4.1714	4.1714		5.8706	4.7036	4.0524	5.4524
12	3.9574	4.6104		5.8100	.5072	3.2257	5.5308
13	3.1404	6.2569		5.8100	.2619	3.1404	5.5308
14	5.5307	7.2704	2.7869	5.6900	5.0841	2.6371	5.5308
15	6.0115	7.0124	8.3102	5.6701	5.0353	2.4798	1.5838
16	5.7695	7.0124	9.3030	5.5706	6.5052	3.0682	
17	6.0115	6.0115	9.4440	5.5308	6.5052	4.6236	
18	6.0115	5.2955	9.3089	5.6640	6.7572	5.7696	
19	5.5307	4.6104	1.9353	5.7108	6.7153	6.0124	
20	5.5307	4.8351	3.4357	5.2956	6.6312	6.2568	
21	3.6417	4.6104	7.7964	5.5308	6.6312	6.1140	
22		3.5411	6.5418	5.8908	6.1752	5.7898	
23	1.0241	3.7474	6.5310	5.4132	6.1344	5.7099	
24	7.0124	4.1714	7.7964	5.1991	6.1344	5.7696	
25	6.5056	3.5411	7.2737	5.1026	5.7298	5.6502	
26	6.7573	3.5411	9.1154	5.0640	5.8908	5.6502	
27	5.2955	3.7474	9.1620	4.4264	6.0120	5.9312	
28	5.7000	4.6104	8.9756	4.3896	6.0120	6.1548	
29	8.6067	4.3890	8.7444	4.5736	5.1816	6.2160	
30	7.5316	5.2955	8.1898	4.5184	4.4816	6.0732	
31	6.7573		6.5484	4.3714		5.9113	
Total	158.5276	157.8507	166.3394	177.0682	118.5954	158.0537	68.2443

This gives a total for the season of 1,235.1393 acre-feet used on 80 acres, or a layer of water 15.44 feet deep over the entire surface.

The small size of the holdings in this division also tends to the use of a large quantity of water. It has been the observation here that the man with 640 acres of land uses water with less waste than the man with 40 acres. This is due to the fact that any waste of water from one tract can be caught up in ditches and used beneficially on others where one man controls a large number of tracts. The custom of running small streams constantly to consumers for stock and domestic puposes has caused much loss of water and has done a great deal toward the "subbing" (water logging) of the land. In one instance in particular, in division No. 2, where a small stream of water has been run constantly during former years along high ground, a small valley below had to be abandoned on account of excess of water. This year the stream was run only during actual irrigation, and the effect can be plainly seen in the valley below in the disappearance of the water from the surface.

The following table gives the area irrigated and the water used during the past s[illegible] No. 1:

Acreage of crops, and water delivered, for the year ended October 1, 1899, division No. 1, Pecos Irrigation and Improvement Company.

[Yield, where given, estimated.]

Name.	Location.	Soil.	Acreage of crops. Alfalfa.	Corn.	Beets.	Cane.	Orchard.	Vines.	Garden.	Beans.	Trees.	Total.	Water delivered. March.	April.	May.	June.	July.	August.	September.	Total.	Depth of irrigation.	Remarks.
													Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Feet.*	
Anderson, W. R.	La Huerta, lot 1 in block 9.	Sandy	5									5	1.46	2.97	3.96	5.01	.....	5.64	8.72	30.76	6.15	Pasture.
Bisa Eddy	La Huerta, lots 5 and 6 in block 9.	do	12									12	21.84	41.63	16.85	.55	1.04	41.97	18.82	142.70	11.89	Alfalfa yield, 3 tons.
Bryant, F. E.	SE. ¼ SW. ¼ and SW. ¼ SE. ¼ sec. 19, T. 21, R. 27 E.	do	35	12		12	5					64	72.84	68.39	122.92	83.62	78.39	154.87	103.64	684.67	10.69	Alfalfa yield, 3 tons. Cane good.
Crawford, A. J.	N. ½ NE. ¼ sec. 12, T. 22, R. 26 E.	Adobe	50			18						68	6.20	20.23	29.14	34.63	36.22	5.70	.81	132.93	1.95	Cane good. Alfalfa pastured.
Carlsbad town	Sec. 6, T. 22, R. 27 E.	Sandy									100	100	22.74	58.82	70.88	53.67	47.40	68.81	54.67	376.99	3.76	
Cameron, J. O.	La Huerta, lot 5 in block 11.	do	4				1					5	.....	7.13	.74	2.92	5.87	4.84	5.18	26.68	5.33	
Draper, E. F.	La Huerta, lot 11 in block 7.	do	2				1					3				7.30	2.22	.....	1.87	11.39	3.76	
Freeman, A. A.	La Huerta, lots 1 and 3 in block 11.	do	9				2		1			12	26.14	16.23	15.11	23.28	15.37	40.19	18.64	154.96	12.91	Alfalfa yield, 3 tons.
Hagerman, J. J.	S. ½ sec. 5, T. 22, R. 27 E.	do	40	15			20				5	80	62.45	168.00	147.99	131.43	149.07	157.32	109.47	925.73	11.57	Poor crop.
La Huerta	S. ½ and S. ½ N. ½ sec. 30, T. 21, R. 27 E.	do									20	20						22.67	95.05	117.72	5.88	Cottonwood trees.
Linington, C. G.	SW. ¼ SW. ¼ sec. 6, T. 22, R. 27 E.	Adobe	38				2					40	38.70	27.24	32.65	26.30	.....	10.53	25.22	160.64	4.00	Poor crop.
Love, R. P.	La Huerta, lot 6 in block 12.	Sandy	1				5					6	3.46	4.45	1.99	1.21	1.38	5.83	5.03	23.35	3.89	Fair peach crop.
Lynne, E. C. (Tansill).	La Huerta, block 6	do		5			30	3	1	4		43	1.48	.....	17.55	.....	8.72	15.75	.....	43.50	1.01	Poor crop.
McLenathen, C. H.	La Huerta, lot 1 in block 5.	do	4						1			5	8.42	1.99	.50	8.21	6.14	6.90	2.73	34.89	6.97	
Do.	SE. ¼ SW. ¼ sec. 7, T. 22, R. 27 E.	do	10	20		10				5		45	12.97	34.02	26.87	53.19	25.84	67.31	48.41	268.61	5.98	Alfalfa yield, 2.5 tons. Good corn and cane.
McElvain, T. N.	La Huerta, lots 2 and 4 in block 12.	do						15				15	.....	52.29	.....	28.46	.....	.....	.....	80.75	5.38	
Miller, M. D.	La Huerta, lots 5 and 7 in block 12.	do		8			1	1				10	5.20	.....	10.15	1.95	.....	29.59	1.01	47.90	4.79	Good corn and cane.

Motter, E. S.	La Huerta, lot 1 in block 8.	....do					5					5	4.95	5.29	16.99	10.25				37.48	7.49	Good peach crop.
Osborne, I. S.	N. ½ NW. ¼ sec. 7, T. 22, R. 27 E.	Adobe	60	20								80	26.93	56.39	69.55	88.81	63.92	104.04	61.47	473.11	5.91	Good alfalfa. Corn yield, 25 bushels.
Quiñones	Phœnix, lot 6	Sandy							1			1		2.33						2.33	2.33	
Rayoux, A.	La Huerta, lot 10 in block 10.	do	5	2		5			1			13	11.40	9.42	13.75	33.77	26.22	23.48	13.22	133.26	10.25	Good cane.
Reding, M. (Eddy).	NE. ¼ NW. ¼ and NW. ¼ NE. ¼ sec. 19, T. 21, R. 27 E.	....do	17	14			5		2			38	26.06	37.20	51.06	90.16	9.75	69.41	13.49	297.12	7.81	Do.
Rio Vista	NW. ¼ SW. ¼ sec. 31, T. 21, R. 27 E.	....do	2				2		1			5	9.87	12.33	12.33	13.24	11.92	15.86	3.45	79.05	15.81	
Rogers, I. W.	La Huerta, lot 6 in block 8.	....do	4									4		5.60	3.22	8.87		6.50		24.19	6.04	Pasture.
San Jose	NW. ¼ SE. ¼ NW. ¼ sec. 7, T. 22, R. 27 E.	....do		6					3			9	1.98	5.94	13.87	20.79	17.24	34.08	11.79	105.69	11.74	
Sharpe, M.	La Huerta, lots 1 to 6 in block 14.	....do		8		4	18		1			31	11.89		26.16	27.74	35.73	27.66	41.00	170.18	5.49	Heavy peach crop.
Swanson (Eddy)	E. ½ SW. ¼ and W. ½ SE. ¼ sec. 31, T. 21, R. 27 E.	....do	40	15	5		2		1			63	70.49	91.42	92.70	90.65	71.75	94.60	184.26	695.87	11.05	Corn poor. Alfalfa pastured.
Tansill, R. W.	La Huerta, lots 3, 5, and 7 in block 8.	....do	15									15	11.56	23.05	13.62	19.00	22.70	49.87	33.72	173.52	11.56	Poor alfalfa (new seeding).
Thomas, Mrs. R.	La Huerta, lot 8 in block 10.	....do					2					2	5.20		2.28		9.10	3.06	2.40	21.99	10.99	
Tracy, F. G.	La Huerta, lot 2 in block 8.	....do	4									4	2.72	2.15	4.24	1.44	3.12	10.16	1.06	24.89	6.22	
Tucker	NE. ¼ NE. ¼ sec. 13, T. 22, R. 26 E.	....do	1			1	1					3	2.31	.98		1.38			.47	5.14	1.71	
Wardman, Geo.	La Huerta, lots 9 and 11 in block 4.	....do	12			3	1					16	18.34	5.57	23.92	26.81	24.17	27.90	28.48	155.19	9.64	
Watkins, W. A.	SW. ¼ SW. ¼ sec. 1, T. 22, R. 26 E.	....do	20									20	16.69	8.77	26.11	19.65	59.66		37.91	168.79	8.43	Fair alfalfa.
Wersell (Eddy)	SW. ¼ SW. ¼ and SW. ¼ NE. ¼ sec. 30, T. 21, R. 27 E.	....do	34	8	5		10		1	1		59	44.85	7.18	87.05	61.34	94.96	78.11	30.42	403.41	6.82	Alfalfa pastured.
Webster, G. H.	SE. ¼ sec. 12, T. 22, R. 26 E.	Adobe	39	45	20	15				10		129		23.87	113.81	141.24	102.26	118.14	64.78	564.10	4.37	Beets fair. Corn yield, 20 bushels.
Wilson	La Huerta, lot 6 in block 11.	Sandy	4									4	.25	.99	1.49	1.86		13.51		18.10	4.52	
Wolfrom, L.	SW. ¼ SE. ¼ sec. 7, T. 22, R. 27 E.	....do	17									17	21.36				1.77	28.89	29.26	81.27	4.78	Fair alfalfa (new seeding).
Yturaldi, Reyes	NE. ¼ NE. ¼ sec. 1, T. 22, R. 26 E.	....do		20								20		26.65		8.24	18.07	13.41	11.12	77.49	3.87	Corn yield, 30 bushels.
Total			484	198	30	68	113	19	14	20	125	1,071	573.25	830.52	1,069.45	1,126.96	952.00	1,356.50	1,067.57	6,976.34	6.51	

DIVISION NO. 2.

In division No. 2 the soil is nearly all sandy loam, and in many instances is very shallow. It is underlaid with limestone and drains well. There is some land along the river bottom that has been slightly "subbed," but drainage by means of open drains is overcoming this difficulty. Where the soil is shallow it requires frequent irrigation, the subsoil furnishing a drain. Such land will always need considerable water, but in many instances this need could be materially lessened by proper cultivation and better methods of irrigation. Flooding is the method of irrigation practiced almost entirely throughout the valley, and in many instances the "lands," as the areas irrigated from a single lateral are called, are laid out so broad and long that great loss takes place from evaporation. On the farm of R. J. Bolles, in this division, the "lands" were 75 feet wide and some of them 2,000 feet in length. It is easy to imagine the great loss of water from a small stream spreading out over an area of nearly 2 acres of land, heated almost to the burning point by a blazing summer sun, when evaporation from a body of water 3 feet deep ran up as high as three-fourths of an inch. In the hot summer days it took a constant flow of nearly 2 cubic feet of water per second twelve hours to cross one of these "lands." The present manager of this farm has cut some of these areas into smaller tracts, and intends making further improvements along this line. The soil naturally requires less water than much land elsewhere in the district, yet during the season more was used. The improvements now contemplated by the manager will undoubtedly change its place from the head of the list as a water user to a position near the bottom.

This division seems very well suited to fruit culture. Beets did not do well in former years, and very few were planted during 1899. The condition of alfalfa varies; it does well on soil of good depth, but not on the shallow soil. Indian corn does fairly well, but the head corns—Kafir, Egyptian, and millo maize—do exceedingly well.

The results of the measurements in this division for the past season are given in the following table:

Acreage of crops and water delivered for the year ended October 1, 1899, division No. 2, Pecos Irrigation and Improvement Company.

Name.	Location.	Soil.	Acreage of crops.										Water delivered.									Remarks.
			Alfalfa.	Corn.	Beets.	Cane.	Orchard.	Vines.	Garden.	Beans.	Trees.	Total.	March.	April.	May.	June.	July.	August.	September.	Total.	Depth of irrigation.	
													Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Feet.	
Bolles, R. J	Sec. 2, T. 23, R. 27 E.	Adobe.	300							25	5	330	11.02	361.87	285.32	352.67	266.46	488.56	299.07	2,064.97	6.25	Alfalfa yield, 2 tons (estimated).
Do	S. ½ and NW. ¼ SW. ¼ sec. 35, T. 22, R. 27 E.	...do..	60									60	195.66	36.06	29.82	19.47	69.48	6.52	65.97	422.98	7.05	
Bradley, J. D.	NE. ¼ NW. ¼ sec. 35, T. 22, R. 27 E.	...do..	16	16		6						38			24.42	35.21	23.24	60.71	7.22	150.80	3.96	Poor crop.
Brenis, K	SE. ¼ NW. ¼ sec. 35, T. 22, R. 27 E.	...do..	9	27		1						37		7.05	35.20	12.50	35.73		10.35	100.83	2.72	Good crop.
Crawford, A. J	S. ½ SE. ¼ and N. ½ SW ¼ sec. 22, T. 22, R. 27 E.	...do..	135									135	63.74	59.92	114.31	89.43	81.91	20.46	53.71	483.48	3.58	Alfalfa pastured.
Daugherty, W. F.	SW. ¼ NW. ¼ sec. 27, T. 22, R. 27 E.	...do..	23	12		1						36	27.38	.01	51.63	41.68	18.45	34.31	28.68	202.09	5.61	Fair crop.
Do	NE. ¼ NE. ¼ sec. 35, T. 22, R. 27 E.	...do..	20									20			42.82	.07	36.28			79.17	3.95	Pasture.
Demorest, C. J	SW. ¼ SW. ¼ sec. 27, T. 22, R. 27 E.	Sandy.	28	1			2			1		32	25.06	42.45	31.05	34.29	32.95	62.27		228.07	7.12	Poor crop.
Do	SW. ¼ NW. ¼ NW. ¼ sec. 35, T. 22, R. 27 E.	Adobe.	3	2								5					3.63	.83		4.46	.89	Alfalfa fair.
Galton, H. E	NW. ¼ NE. ¼ sec. 35, T. 22, R. 27 E.	...do..	29	9								38	10.14	9.02	41.84	26.37	10.78	53.25	65.78	217.18	5.71	Do.
Kayser, S. G.	NE. ¼ sec. 27, T. 22, R. 27 E.	...do..	130	17		45						192	304.82	69.88	72.00	143.32	113.15	153.29	263.73	1,120.19	5.83	Alfalfa good.
Love, R. P	E. ½ SE. ¼ SE. ¼ sec. 8, T. 22, R. 27 E.	Sandy.	14	3								17	11.27	.31	16.72		11.65	13.71	9.99	63.65	3.74	Do.
McKenzie, E. D.	SE. ¼ SW. ¼ sec. 27, T. 22, R. 27 E.	Adobe.	12	22						6		40	13.17	20.30	29.80	45.82	28.62	49.13		186.84	4.67	Fair crops.
Do	NW. ¼ SW. ¼ sec. 27, T. 22, R. 27 E.	...do..	17	20						1		38	29.84	7.70	33.96	11.16		12.18	38.70	133.54	3.51	Do.
Do	NW. ¼ NE. ¼ sec. 34, T. 22, R. 27 E.	...do..	12	22								34		16.89	2.37	52.51	35.64	46.23	14.47	168.11	4.94	Do.
Do	SE. ¼ SW. ¼ sec. 34, T. 22, R. 27 E.	...do..	22									22			29.70	26.16		41.83	6.60	104.29	4.51	Do.
McGinnis	S. ½ SE. ¼ sec. 9, T. 22, R. 27 E.	Sandy.	20									20							66.90	66.90	3.84	Just sown.
Menoud, E.	NE. ¼ NW. ¼ sec. 1, T. 23, R. 27 E.	...do..	25	10		2				1		38		23.65	40.07		24.97	24.44	24.80	187.98	3.62	Fair crops.

Acreage of crops and water delivered for the year ended October 1, 1899, division No. 2, Pecos Irrigation and Improvement Company—Continued.

Name.	Location.	Soil.	Acreage of crops.										Water delivered.								Depth of irrigation.	Remarks.
			Alfalfa.	Corn.	Beets.	Cane.	Orchard.	Vines.	Garden.	Beans.	Trees.	Total.	March.	April.	May.	June.	July.	August.	September.	Total.		
													Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Acre-feet.	Feet.	
Mihlferd, John	NW. ¼ SW. ¼ NW. ¼ sec. 35, T. 22, R. 27 E.	Adobe		5		4						9			2.39	2.49	4.78	8.58		18.24	2.02	Good crops.
Mullane, W. H.	NE. ¼ NE. ¼ sec. 33, T. 22, R. 27 E.	do	1	2	4		1					8			6.52	12.14	3.84	2.56	15.04	40.10	5.01	Failure.
Rarey, J. F.	E. ½ NE. ¼ and NE. ¼ SE. ¼ sec. 28, T. 22, R. 27 E.	do	15	105		14	5					139	19.03	69.33	43.52	87.93	86.76	143.76	132.14	582.47	4.19	Alfalfa poor; corn fair.
Do.	S. ½ SW. ¼ sec. 22, T. 22, R. 27 E.	do	10	70								80	32.90		69.23	89.12		38.72	21.71	251.68	3.14	Do.
Scoggins, Ed.	SW. ¼ NE. ¼ sec. 35, T. 22, R. 27 E.	do	3	28		4						35		17.51	13.20	17.72	29.40	57.09		134.92	3.85	Good corn.
Stokes, J. W.	SW. ¼ SE. ¼ sec. 24, T. 22, R. 27 E.	Sandy	25	20		2	12					59		23.59	46.73	14.79	11.61	22.76	46.10	165.58	2.80	Good corn and alfalfa.
Telford, Jack	NW. ¼ SE. ¼ sec. 27, T. 22, R. 27 E.	do		40								40		12.24	8.53			34.73		85.50	2.13	Good corn.
Foote, J. B.	SW. ¼ NW. ¼ sec. 34, T. 22, R. 27 E.	Adobe	25	11					2			38	38.61	6.41	37.68	16.03	38.59	65.54	44.54	247.40	6.51	Fair corn.
Tracy, F. G.	SW. ¼ SE. ¼ sec. 10, T. 22, R. 27 E.	Sandy	14	20	20	5	17		1			77		13.96	44.39	54.02	22.45	50.08	20.35	235.25	3.05	Fair crop; heavy peach crop.
Webster, G. H.	Sec. 21, T. 22, R. 27 E.	Adobe	208	75				30	2			315	106.51	364.70	259.39	37.84	95.35	186.86	140.82	1,191.47	3.78	Alfalfa fair (new seeding); corn good.
Wilson, W. A.	SE. ¼ SE. ¼ sec. 26, T. 22, R. 27 E.	do	20	7		10						37		5.39	19.29	9.05	10.36	36.61	22.31	103.01	2.78	Corn fair; alfalfa new seeding.
Wilson, W. B.	SW. ¼ SE. ¼ sec. 26, T. 22, R. 27 E.	do	30	8	3		3					44	.79	.69	14.50	28.05	11.40	7.48	16.48	79.39	1.80	Corn fair; alfalfa pastured.
Wright, C. H.	NW. ¼ NW. ¼ sec. 27, T. 22, R. 27 E.	do	5	7			5					17	17.41	.02	12.72	8.71	13.29	32.83		84.98	4.99	
Wright, C. W.	do	do	5									5	6.23			10.67	.18	9.69	6.38	33.15	6.63	Good alfalfa.
Yturaldi, S. A.	S. ½ NE. ¼ and N. ½ SW. ¼, sec. 1, T. 23, R. 27 E.	do	50	35						10		95		67.29	62.61	49.62	18.32	107.85	157.57	463.26	4.87	Poor alfalfa; good corn and beans.
Total			1,286	594	27	94	45	30	5	44	5	2,130	913.56	1,296.24	1,521.73	1,328.84	1,139.27	1,872.86	1,579.36	9,651.86	4.53	

DIVISION NO. 3.

This is a division of the greatest successes and worst failures. The soil is a heavy clay loam and has a greater depth than that of divisions No. 1 and No. 2. It is here that the best alfalfa, beets, and head corns have been raised, while on the other hand the same crops have been complete failures upon the same land. The soil is heavy and capable of producing good crops under a proper system of irrigation, but handled as a great deal of it has been it becomes a marsh. The soil does not drain naturally, and the large amounts of water that have been applied have literally submerged it until now some of it is bare of vegetation. The general fall is amply sufficient for a good system of underdrainage, and when such drainage is provided and intelligent care exercised in future applications of water it will make the most productive section under this system.

The area irrigated and the water used in this division is shown by the following table:

Acreage of crops and water delivered for the year ended October 1, 1899, division No. 3, Pecos Irrigation and Improvement Company.

[Yield, where given, estimated.]

Name	Location	Soil	Acreage of crops. Alfalfa.	Corn.	Beets.	Cane.	Orchard.	Vines.	Garden.	Beans.	Trees.	Total.	Water delivered. March.	April.	May.	June.	July.	August.	September.	Total.	Depth of irrigation.	Remarks.
													Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Ft.*	
Abalos, B	SW. ¼ sec. 18, T. 23, R. 28.	Adobe	15	80	30	4			1			130		72.43	96.61	30.05	56.33	51.23	20.71	338.36	2.60	Failure; land subbed.
Anderson, W. W.	SW. ¼ NE. ¼ sec. 22, T. 23, R. 28.	Sandy	15	10	10							35		54.07	22.07	33.52	2.71	31.44	4.03	147.84	4.22	Failure.
Becerra, S. P.	NW. ¼ NE. ¼ and SW. ¼ NE. ¼ sec. 17, T. 23, R. 28.	Adobe	2	15	10	5			1	10		43			13.95	20.99	88.93	40.31	23.19	187.37	4.36	Failure; Mexican cultivator.
Benson, R. S.	Sec. 7, T. 23, R. 28.	...do...	520	80			20	5	1			626	72.07	337.80	328.61	243.92	127.85	203.77	164.86	1,478.88	2.36	Alfalfa yield 4 tons.
Do.	N. ½ NW. ¼ sec. 21, T. 23, R. 28.	...do...				80						80		37.77		1.06	62.07	31.26		132.16	1.65	
Bustamante, M.	SW. ¼ NE. ¼ sec. 12, T. 23, R. 27.	...do...			12				1			13				9.94		11.18	5.21	26.33	2.02	Beets yield 6 tons.
Calvani, T.	N. ½ SW. ¼ sec. 15, T. 23, R. 28.	Sandy	6	18	19	6			1	3		53	51.77	67.89	37.95	25.55	36.44	12.25	25.46	257.31	4.85	Fair crop.
Corrales, P.	N. ½ SE. ¼ sec. 17, T. 23, R. 28.	Adobe	12	14	40				1	2		69	5.72	66.87	41.55	41.55	41.08	37.00	26.49	259.86	3.76	Fair corn crop; beets a failure.
Dishman, C.	SE. ¼ NE. ¼ SW. ¼ sec. 21, T. 23, R. 28.	...do...		9					1			10			11.12	8.39	9.48	12.18		41.17	4.11	Corn yield 40 bushels.
Dearsley, Dick	NW. ¼ sec. 12, T. 23, R. 27.	...do...	22	60	31	3			1		2	119	39.74	17.87	26.21	63.02	30.49	66.16	65.10	308.59	2.52	
Dunaway, J. F.	SW. ¼ sec. 16, T. 23, R. 28.	Sandy	50	20	30				1	5		106	23.99	81.67	98.81	89.24	100.64	15.02	76.84	481.21	4.54	Corn good; alfalfa pastured; beets yield 4.5 tons.
Galton, W. W.	SW. ¼ SW. ¼ sec. 6, T. 23, R. 28.	...do...	35	3		5	1					44	9.91	12.91	15.09	27.98	21.48	30.40		117.69	2.67	Cane good, alfalfa yield 4 tons.
Garza, E. (Bolles)	N. ½ and NW. ¼ sec. 20, T. 23, R. 28.	Adobe	24	218	150					20		412	5.86	147.29	123.57	150.81	157.30	166.56	72.66	825.18	2.00	Failure.
Do.	N. ½ NW. ¼ and SE. ¼ NW. ¼ sec. 18, T. 23, R. 28.	...do...	35	12	40	3						90	23.61	65.96	27.29	59.92	19.47	29.26	44.76	210.62	2.45	Do.
Gomez, C.	S. ½ SE. ¼ sec. 17, T. 23, R. 28.	...do...	34	6	32				1			73	21.33	53.87	10.78	29.44	33.95	40.98	9.82	201.67	2.76	Alfalfa poor; beets yield 6 tons.
Grandi, A.	SE. ¼ sec. 1, T. 23, R. 27.	...do...	20	12	35	3			1	2		73	6.99	73.55	64.26	40.17	18.22	54.98	14.78	282.94	3.87	Beets poor; corn yield 30 bushels.

hall not be liable in any way for the shortness or insufficiency of supply occasioned by any of said causes.

(8) And the second party agrees, in consideration aforesaid, to waive, and hereby does waive, any and all claims for loss or damage by reason of any leakage, seepage, or overflow from any canal or ditches, or from any reservoirs, lakes, or laterals of the first party, either upon the land aforesaid or any other tract belonging to said party, anything in any statute, law, or custom to the contrary notwithstanding.

(9) The second party shall construct and maintain in good order and repair a ditch upon said land, of such size and grade and at such point and location as shall be prescribed by the first party, to catch and conduct to some main lateral ditch of the first party all waste water flowing upon said tract of land.

The regular field force of this system during the irrigating season consists of a watchman at each reservoir whose duty it is to keep records of the height of water in the reservoir, the amount discharged through the canals and spillways, note condition of the works and keep everything in order, and regulate the flow into the canal as directed from the engineer's office; and four ditch riders, each in charge of a certain portion of the main canal and the laterals from it. Their duties are to deliver the water to the consumers and keep a record of all such deliveries. For this purpose they are provided with a book of slips, two to the page, one detachable. At the end of each delivery the two slips are filled out in duplicate, one detached and sent to the engineer's office, the other remaining as a stub in the book and sent in when the book is filled. The following is a copy of this slip:

Pecos Irrigation and Improvement Company.

Department of chief engineer. Record of water delivery.

Division No., ——, ———. Name of owner, ———, ———. Water right No., ——. Weir, ——. Width, ——. Depth, ——. Date, ——, from ——, —. m. to ——, —. m. Time in hours, ——. Acres irrigated, ——. Variety of crops, ———. Method of irrigation, ———. Nature of soil, ———. Condition of owner's laterals, ———. Remarks, ———. Total, acre-feet, ———.

The measurements are made over weirs, and are not absolutely accurate, as at present there are no automatic registers for determining the head. But as the whole system is connected by telephone, and all water is drawn from or returned to the canal under instructions from the engineer's office, the heads can be kept very uniform, except the variation due to evaporation, and as the measurements are taken twice daily, the results are at least approximate, and will certainly be of great aid in determining the duty of water.

This is the third season that any attempt has been made here to determine the amount of water actually used, and while it is known that the results are not absolutely accurate they give a comparative record, and, when the necessity of selling water by measurement becomes as apparent to both the seller and the consumer as it is to many engineers, methods of accurate measurement will be adopted, although involving considerable expense.

(2) Said water shall be used only to irrigate the lands above described and for domestic purposes, and stock kept thereon, and under no circumstances shall the same, or any part thereof, be used for mining, milling, or mechanical power, or any other purpose not directly connected with, or incidental to, the purposes first herein mentioned.

(3) The first party shall not be required to furnish a greater amount of water limited to each water right above stated than may be reasonably necessary for the production of good average crops under skillful irrigation and cultivation, and the other uses above allowed.

(4) The second party shall not permit said water to be furnished as aforesaid to run to waste, but as soon as a sufficient quantity shall have been used, for the time being, for the purposes herein allowed, shall, in such manner as the first party may prescribe, notify said first party that the said water may be shut off.

(5) The said water shall be delivered by the first party into a lateral ditch or subsidiary canal provided by the second party and connected with the said main canal, or with a lateral or subsidiary canal of the first party; and the manner of delivering, measuring, and regulating the supply of water to the second party shall be prescribed by the first party and at all times under its control; and if the second party shall in any manner change, open, or shut any measuring box, or by any means increase or diminish the aperture thereof, without the consent of the first party; or, in case the second party shall use a supply of water for any other lands, or shall allow any person to use it, except for the purposes herein allowed, upon the above-described premises, or shall in any way whatever take water from any ditch, canal, lateral, or sublateral supplied with water by the first party, except as delivered by the first party, then the second party shall, at the option of the board of directors of the first party, forfeit all right to receive water from the first party for the then current year, and also all moneys paid as compensation for furnishing water for said year.

(6) It is further agreed that if, by reason of any cause, the supply of water shall be insufficient to fill and flow through said main canal according to its estimated capacity, or insufficient to furnish the amount which all the consumers may be entitled to, then the first party shall have the right to distribute such water as may flow through said canal, pro rata, to all persons entitled thereto, and for the purpose of so doing may establish and enforce such rules and regulations as it may deem necessary or expedient; but in case of such pro rata distribution credit shall be given the owner or owners of the water rights hereby granted at a proportionate rate of annual water rental for the amount of water less than 43,560 cubic feet per acre which may have been needed and required by the owner of such water right for purposes herein recognized, but which the first party, on account of such pro rata distribution, may not have furnished; which credit shall be given upon the amount due as compensation for furnishing water to the party who is the owner of the water right upon which the credit is due, at the next semiannual period for the payment of said compensation. And the first party shall have the right to turn the water out of said main canal, and shut the water out of the lateral and service ditches, at any time for the purpose of cleaning or repairing said main canal, its dam or reservoir, or for repairing or putting in new or other wasteweirs, headgates, wastegates, service gates, bridges, or any of the appurtenances of said canal, and during the time occupied thereby the right of the second party to demand and receive water hereunder shall be suspended.

(7) It is hereby distinctly understood and agreed by and between the parties hereto that in case the canals of said first party through which the water rights herein granted are furnished water shall be unable to carry and distribute a volume of water equal to their estimated capacity, either from casual, unforeseen, or unavoidable accident, or the act of God, or if the volume of water proves insufficient from drought, or from any other cause beyond the control of said first party, the first party

shall not be liable in any way for the shortness or insufficiency of supply occasioned by any of said causes.

(8) And the second party agrees, in consideration aforesaid, to waive, and hereby does waive, any and all claims for loss or damage by reason of any leakage, seepage, or overflow from any canal or ditches, or from any reservoirs, lakes, or laterals of the first party, either upon the land aforesaid or any other tract belonging to said party, anything in any statute, law, or custom to the contrary notwithstanding.

(9) The second party shall construct and maintain in good order and repair a ditch upon said land, of such size and grade and at such point and location as shall be prescribed by the first party, to catch and conduct to some main lateral ditch of the first party all waste water flowing upon said tract of land.

The regular field force of this system during the irrigating season consists of a watchman at each reservoir, whose duty it is to keep records of the height of water in the reservoir, the amount discharged through the canals and spillways, note condition of the works and keep everything in order, and regulate the flow into the canal as directed from the engineer's office; and four ditch riders, each in charge of a certain portion of the main canal and the laterals from it. Their duties are to deliver the water to the consumers and keep a record of all such deliveries. For this purpose they are provided with a book of slips, two to the page, one detachable. At the end of each delivery the two slips are filled out in duplicate, one detached and sent to the engineer's office, the other remaining as a stub in the book and sent in when the book is filled. The following is a copy of this slip:

Pecos Irrigation and Improvement Company.

Department of chief engineer. Record of water delivery.

Division No., ——, ———. Name of owner, ———, ———. Water right No., ——. Weir, ——. Width, ——. Depth, ——. Date, ——, from ——, —. m. to ——, —. m. Time in hours, ——. Acres irrigated, ——. Variety of crops, ———. Method of irrigation, ———. Nature of soil, ———. Condition of owner's laterals, ———. Remarks, ———. Total, acre-feet, ———.

The measurements are made over weirs, and are not absolutely accurate, as at present there are no automatic registers for determining the head. But as the whole system is connected by telephone, and all water is drawn from or returned to the canal under instructions from the engineer's office, the heads can be kept very uniform, except the variation due to evaporation, and as the measurements are taken twice daily, the results are at least approximate, and will certainly be of great aid in determining the duty of water.

This is the third season that any attempt has been made here to determine the amount of water actually used, and while it is known that the results are not absolutely accurate they give a comparative record, and, when the necessity of selling water by measurement becomes as apparent to both the seller and the consumer as it is to many engineers, methods of accurate measurement will be adopted, although involving considerable expense.

Acreage of crops and water delivered for the year ended October 1, 1899, division No. 4, Pecos Irrigation and Improvement Company.

Name	Location	Soil	Acreage of crops. Alfalfa.	Corn.	Beets.	Cane.	Orchard.	Garden.	Trees.	Total.	Water delivered. March.	April.	May.	June.	July.	August.	September.	Total.	Depth of irrigation.	Remarks.
											Ac. ft.	*Ac. ft.*	*Ac. ft.*	*Ac. ft.*	*Ac. ft.*	*Ac. ft.*	*Ac. ft.*	*Ac. ft.*	*Feet.*	
Anderwerth, C. M.	N. ½ SW. ¼ sec. 28, T. 23, R. 28	Sandy	16	35	21	4				76		24.43	14.51	60.03	18.81	43.19	15.76	176.73	2.45	Good crops.
Anderwerth, F.	N. ½ SW. ¼ SW. ¼ sec. 33, T. 23, R. 28	do	2	18	8		3	1		32		12.52	15.32	17.22	5.06	12.43	1.12	63.67	1.99	Fair crops; land subbed.
Ayers, A. M.	SE. ¼ SE. ¼ sec. 10, T. 24, R. 28	do		8				1		9			10.92	2.39		7.54		20.85	2.31	Fair crops.
Beeman, C. W.	SE. ¼ SW. ¼ sec. 3, T. 24, R. 28	do	3	27			2			32		7.47	16.54	8.20	19.40	10.92	10.46	72.99	2.28	Poor crops.
Bowker, H. D.	E. ½ SE. ¼ sec. 11, and SW. ¼ SW. ¼ sec. 12, T. 24, R. 28	do	40	31			10			81		66.96	114.99	10.15	67.55	75.80	60.54	395.99	4.89	Corn fair; alfalfa pastured.
Cadwell, Edw.	SE. ¼ SW. ¼ sec. 32, T. 23, R. 28	do	15							15	9.32		26.19			5.22		40.73	2.71	
Do	SW. ¼ NE. ¼ SW. ¼ sec. 10, T. 24, R. 28	do		5						5				10.02		8.95		18.97	3.79	
Calderon, A.	SE. ¼ NW. ¼ and NE. ¼ SW. ¼ sec. 28, T. 23, R. 28	do			70	8				78		39.33	61.04	63.68	10.46	67.51	9.91	251.93	3.23	Beets fair.
Do	SW. ¼ SE. ¼ sec. 3, T. 24, R. 28	do		15						15		26.88	7.90	8.56	25.15	28.75	24.57	121.81	8.12	
Dishman, C. H.	SW. ¼ SW. ¼ sec. 9, T. 24, R. 28	do	3	7	12		1			23			16.40	2.97	28.58	12.43	8.80	69.38	3.01	
Fletcher & Eakin	N. ½ NE. ¼ sec. 17 and E. ½ SE. ¼ sec. 8, T. 24, R. 28	do	57			2			2	61		15.07	48.06	81.91	20.96	62.41	13.29	250.70	4.99	Alfalfa pastured.
Hakes, Eva	SW. ¼ SE. ¼ sec. 11, T. 24, R. 28	do	8	18			2	1	1	30		24.99	13.03	7.48	10.27	32.09	13.11	100.97	3.36	Fair crops.
Hare, W. H.	S. ½ SE. ¼ SW. ¼ sec. 10, T. 24, R. 28	do					20			20		8.18	3.30	7.61	16.17	8.43	9.52	[illegible]	2.66	
Harkey, D. R.	NE. ¼ SW. ¼ sec. 12, T. 24, R. 27	do	6	2			2			10		12.17	28.77	2.68	3.10	7.43		54.15	5.41	
Hays, J. W.	E. ½ NE. ¼ NW. ¼ sec. 13, T. 24, R. 28	do	1	14		3		1		19			13.22	7.42	7.33	16.99	5.78	50.74	2.67	Good corn.
Hoag, L. N.	NW. ¼ NW. ¼ sec. 13, T. 24, R. 28	do	15				23		2	40		24.20	1.86	24.11	1.56	33.25	2.73	87.71	2.19	Fair crops.
Humiston, H.	SE. ¼ NE. ¼ sec. 15, T. 24, R. 28	do		10			2			12			11.73	14.88	9.12	29.16	8.41	73.30	6.10	Poor crops.
Kahman, A.	SW. ¼ SE. ¼ sec. 27, T. 23, R. 28	do		2	5					7		14.67	25.71	5.95	6.01	14.57	6.36	74.27	10.61	Do.
Kemp, D. L.	N. ½ NE. ¼ and NE. ¼ NW. ¼ sec. 23, T. 24, R. 28	do	40	30	22			1		93	6.83	76.47	105.88	83.78	33.15	82.65	116.10	504.86	5.42	Good crops.
Mays, Mrs. J.	NE. ¼ NE. ¼ NW. ¼ sec. 10, T. 24, R. 28	do		8			2			10	3.02	4.67	9.77	10.04	5.69	7.49		40.68	4.06	
Montgomery, R. A.	NE. ¼ SE. ¼ sec. 10, T. 24, R. 28	do	3	30		2	1			36			39.65	6.16	15.23	24.95	2.73	88.72	2.46	Fair crops.
Nolty, Cris	SW. ¼ SW. ¼ sec. 27, T. 23, R. 28	do			25					25			48.64	21.67		24.84	4.89	99.33	3.98	Failure; land subbed.
Pratt, A. N.	NE. ¼ SW. ¼ sec. 22, T. 23, R. 28	do	6	30				1		37		25.08	54.00	18.18	48.65	56.65	13.98	216.59	5.86	Fair crops.
P. V. B. S. Co.	N. ½ NE. ¼ sec. 28, T. 23, R. 28	do			70					70			49.58	38.12	22.09	11.87	55.10	172.56	2.46	Beets light.
Stamp, Mrs. M. B.	NE. ¼ NE. ¼ sec. 32, T. 23, R. 26	do		7		3				10		.74	13.56	6.28		3.22		22.80	2.28	Poor crops.
Weaver, N. W.	SE. ¼ NE. ¼ sec. 5, T. 24, R. 28	do		18	6	3	13			40			15.22	6.86	4.75		5.90	32.73	.82	Fair crops; some apples first year.
Valles, A.	NE. ¼ NE. ¼ sec. 17, T. 24, R. 28	do	2	20	15					37		4.79	82.47	29.74	17.08	44.18	17.32	151.48	4.09	Poor crops; Mexican farming.
Total			217	398	254	25	81	6	5	928	19.17	[illegible].57	805.46	580.11	406.92	732.27	405.86	[illegible]	3.56	

The rainfall at Carlsbad for the year 1899 was less than during any season since irrigation began in this valley. The monthly precipitation for the year is given below:

Monthly precipitation at Carlsbad, N. Mex., 1899.

	Inch.		Inch.
January	0.00	July	0.08
February	.02	August	.00
March	.06	September	.08
April	.08	October	.03
May	.00	November	.18
June	.13		

The following table shows the depth of water received by the land in the four divisions from both irrigation and rainfall, from March to September, inclusive:

Duty of water under Pecos Canal, measuring water at heads of laterals.

	Div. No. 1.	Div. No. 2.	Div. No. 3.	Div. No. 4.
Area irrigated ... acres	1,071	2,130	4,757	923
Water used ... acre-feet	6,976.34	9,651.88	14,046.63	3,288.36
Depth of irrigation ... feet	6.51	4.53	2.95	3.56
Depth of rainfall ... do	.43	.43	.43	.43
Depth of irrigation and rainfall ... do	6.94	4.96	3.38	3.99

DUTY OF WATER UNDER SOUTHERN BRANCH OF PECOS CANAL.

Not all the water used in the four divisions is measured at the head of the canal, but a record is kept of that passing through the flume across the Pecos and watering the land on the west side of the river. This water irrigates 8,410 acres. The following table gives the results of these measurements:

Water discharged by flume across Pecos River, April 16 to October 31, 1899.

[See diagram, Pl. IV, p. 72.]

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	...	195.0950	342.8513	429.7190	393.9339	378.2479	277.1727
2	...	181.5041	339.1571	427.6364	389.6364	387.7088	271.9180
3	...	299.1157	338.8596	413.9008	386.2975	382.6802	242.9520
4	...	301.7273	333.0000	381.3884	386.0248	380.5511	177.9687
5	...	318.8265	327.5703	384.5123	386.5702	370.0089	6.1846
6	...	336.8512	323.5703	400.0082	387.3885	359.5825	0
7	...	337.5620	317.6194	421.5374	388.1157	355.3024	50.8560
8	...	329.3058	305.8679	326.8512	389.1157	336.1610	113.4150
9	...	325.2975	291.4380	46.3636	389.7521	284.2470	53.5480
10	...	316.0413	284.9256	0	388.8430	234.5950	46.1660
11	...	345.2975	275.8512	0	387.3884	0	44.9800
12	...	339.4298	246.7769	118.0000	394.1901	25.9421	44.5080
13	...	337.3967	270.8512	424.5868	410.0000	198.8099	43.5640
14	...	330.4050	335.8760	447.0744	408.8760	219.9669	43.8000
15	...	327.8595	384.9093	408.7521	407.2397	222.7107	47.1240
16	181.0000	340.6860	389.9008	367.5371	405.7851	227.7190	51.4200
17	162.4298	345.7355	399.3719	374.3884	408.0496	229.4545	51.9030
18	145.9174	350.2727	379.3141	243.1653	418.4114	233.6529	52.3890
19	142.2808	354.2562	384.1983	37.8099	415.2397	234.0165	50.4600
20	143.4380	350.0992	390.4298	246.7768	416.1983	238.8678	48.7800
21	149.4711	354.0000	387.2314	323.9504	411.1736	258.4215	49.5000

Water discharged by flume across Pecos River, April 16 to October 31, 1899—**Continued.**

[See diagram, Pl. IV, p. 72.]

Day.	April.	May.	June.	July.	August.	September.	October.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
22	174.1612	355.5620	363.6281	385.4380	409.7851	260.6281	49.7400
23	190.7934	352.4628	375.2727	377.8763	407.8306	247.2945	50.4600
24	190.0950	350.4504	373.8512	359.4380	403.9504	235.1854	49.0200
25	202.4215	359.3058	369.5207	351.2727	401.0579	230.3874	47.8280
26	190.9422	355.1405	370.8678	348.6281	399.2727	227.6589	47.8520
27	197.9669	335.9109	340.8595	346.7107	396.8926	233.8504	47.1140
28	227.3554	326.6804	326.6694	349.0165	393.9174	273.8720	46.4000
29	229.4463	335.8512	407.4959	360.2562	391.5702	277.5922	45.9240
30	227.3058	314.5289	429.9174	369.1240	386.4793	278.3887	47.8520
31	....	341.5041	....	373.9504	382.7107	....	47.7280
Total	2,755.0248	10,174.1615	10,402.6531	9,845.6694	12,341.1966	7,822.8992	2,247.5270

Duty of water under southern branch of Pecos Canal, measuring water at the Pecos flume.

Area irrigated	acres..	8,410
Water used	acre-feet..	55,589.1316
Water used per acre	acre-feet..	6.61
Rainfall, April to October	feet..	.40
Total depth, irrigation and rainfall	do...	7.01

The duty of water as indicated by this year's investigations in the Pecos Valley is very low. The farmers have had all the water they wanted and in many instances much more than they needed. When the majority realize how much damage is done by the improper use of water, and when water becomes scarce enough to be sold by measure, the duty in this valley will be greatly increased.

LOSS OF WATER IN CANALS.

While farmers have had all the water they wanted and have used it wastefully, much has been lost from the canal before reaching the headgates of the laterals. There are no exact records of this loss, but it may be approximated by taking the difference between the flow of the canal at the flume and the quantity of water delivered to users below that place.

The two records are complete only for the months of May, June, July, August, and September. During these months the water delivered to the land under this canal, as shown by the tables for the several divisions, was as follows:

Water delivered to land under Southern Canal, May 1 to September 30, 1899.

	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
First division	487.95	551.79	456.05	561.86	533.62
Second division	1,521.73	1,328.84	1,139.27	1,872.86	1,579.36
Third division	2,324.18	2,602.54	2,222.68	2.477.96	1,582.91
Fourth division	805.46	530.11	405.92	732.27	405.86
Total	5,139.32	5,013.28	4,223.92	5,644.45	4,101.75

The following table shows the proportion of the water passing through the flume which was delivered to the land under the canal below the flume:

Percentage of water delivered.

Month.	Discharge of flume.	Water delivered.	Percentage.
	Acre-feet.	*Acre-feet.*	
May	10,174.16	5,139.32	50.8
June	10,402.65	5,013.28	48.2
July	9,845.67	4,223.92	42.9
August	12,341.20	5,664.45	45.8
September	7,822.90	4,101.75	52.4
Total	50,586.57	24,142.72	47.7

It will thus be seen that less than half the water entering the canal reached the land to be irrigated. This loss is due to evaporation and seepage and faulty construction. Under the present development this water is not needed, and hence the loss is not felt.

TEMPERATURE AND EVAPORATION.

The following table gives the temperature records at Carlsbad for the six months, May to October:

Temperature at Carlsbad, N. Mex., 1899.

Month.	Maximum.	Minimum.	Average maximum.	Average minimum.
	°F.	°F.	°F.	°F.
May	98	41	90.0	54.2
June	102	45	93.2	55.3
July	101	64	93.7	68.0
August	103	64	94.8	67.7
September	99	48	88.1	59.2
October	89	34	78.1	49.2

Records of evaporation were kept for the period from May 1 to November 11. The atmosphere was dry and evaporation was heavy. The table given below shows the evaporation for periods of one week:

Evaporation at Carlsbad, N. Mex., by weeks, 1899.

	Inches.		Inches.
May 1 to 7	1.13	August 13 to 19	2.00
May 8 to 14	2.50	August 20 to 26	1.75
May 15 to 21	4.25	August 27 to September 2	2.00
May 22 to 28	5.25	September 3 to 9	1.25
May 29 to June 3	5.88	September 10 to 16	1.25
June 4 to 10	2.50	September 17 to 23	1.25
June 11 to 17	2.85	September 24 to 30	1.25
June 18 to 24	2.00	October 1 to 7	1.00
June 25 to July 1	1.63	October 8 to 14	1.00
July 2 to 8	2.25	October 15 to 21	1.00
July 9 to 15	2.00	October 22 to 28	.88
July 16 to 22	1.00	October 29 to November 4	.75
July 23 to 29	2.00	November 5 to 11	.75
July 30 to August 5	1.75		
August 6 to 12	1.50	Total	54.62

Acreage of crops and water delivered for the year ended October 1, 1899, division No. 2, Pecos Irrigation and Improvement Company—Continued.

Name.	Location.	Soil.	Acreage of crops.										Water delivered.									Remarks.
			Alfalfa.	Corn.	Beets.	Cane.	Orchard.	Vines.	Garden.	Beans.	Trees.	Total.	March.	April.	May.	June.	July.	August.	September.	Total.	Depth of irrigation.	
													Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Feet.*	
Mihlferd, John	SW. ¼ SW. ¼ NW. ¼ sec. 35, T. 22, R. 27 E.	Adobe		5		4						9			2.39	2.49	4.78	8.58		18.24	2.02	Good crops.
Mullane, W. H.	NE. ¼ NE. ¼ sec. 33, T. 22, R. 27 E.	do	1	2	4		1					8			6.52	12.14	3.84	2.56	15.04	40.10	5.01	Failure.
Rarey, J. F.	E. ½ NE. ¼ and NE. ¼ SE. ¼ sec. 28, T. 22, R. 27 E.	do	15	105		14	5					139	19.03	69.33	43.52	87.93	86.76	143.76	132.14	582.47	4.19	Alfalfa poor; corn fair.
Do.	S. ½ SW. ¼ sec. 22, T. 22, R. 27 E.	do	10	70								80	32.90		69.23	89.12		38.72	21.71	251.68	3.14	Do.
Scoggins, Ed.	SW. ¼ NE ¼ sec. 35, T. 22, R. 27 E.	do	3	28		4						35		17.51	13.20	17.72	29.40	57.09		134.92	3.85	Good corn.
Stokes, J. W.	SW. ¼ SE. ¼ sec. 24, T. 22, R. 27 E.	Sandy	25	20		2	12					59		23.59	46.73	14.79	11.61	22.76	46.10	165.58	2.80	Good corn and alfalfa.
Tedford, Jack	NW. ¼ SE. ¼ sec. 27, T. 22, R. 27 E.	do		40								40		42.24	8.53			34.73		85.50	2.13	Good corn.
Foone, J. B	SW. ¼ NW. ¼ sec. 34, T. 22, R. 27 E.	Adobe	25	11					2			38	38.61	6.41	37.68	16.03	38.59	65.54	14.54	247.40	6.51	Fair corn.
Tracy, F. G	SW. ¼ SE. ¼ sec. 10, T. 22, R. 27 E.	Sandy	14	20	20	5	17		1			77		13.96	14.39	54.02	22.45	50.08	20.35	235.25	3.06	Fair crop; heavy peach crop.
Webster, G. H	Sec. 21, T. 22, R. 27 E.	Adobe	208	75				30	2			315	106.51	364.70	259.39	37.84	95.35	186.86	140.82	1,191.47	3.78	Alfalfa fair (new seeding); corn good.
Wilson, W. A.	SE. ¼ SE. ¼ sec. 26, T. 22, R. 27 E.	do	20	7		10						37		5.39	19.29	9.05	10.36	36.61	22.31	103.01	2.78	Corn fair; alfalfa new seeding.
Wilson, W. B.	SW. ¼ SE. ¼ sec. 26, T. 22, R. 27 E.	do	30	8	3		3					44	.79	.69	14.50	28.05	11.40	7.48	16.48	79.39	1.80	Corn fair; alfalfa pastured.
Wright, C. H.	NW. ¼ NW. ¼ sec. 27, T. 22, R. 27 E.	do	5	7			5					17	17.41	.02	12.72	8.71	13.29	32.83		84.98	4.99	
Wright, C. W.	do	do	5									5	6.23			10.67	.18	9.69	6.38	33.15	6.63	Good alfalfa.
Yturaldi, S. A.	S. ½ NE. ¼ and N. ½ SW. ¼, sec. 1, T. 23, R. 27 E.	do	50	35						10		95		67.29	62.61	49.62	18.32	107.85	157.57	463.26	4.87	Poor alfalfa; good corn and beans.
Total			1,286	594	27	94	45	30	5	44	5	2,130	913.58	1,296.24	1,521.73	1,328.84	1,139.27	1,872.86	1,579.36	9,651.88	4.53	

DIVISION NO. 3.

This is a division of the greatest successes and worst failures. The soil is a heavy clay loam and has a greater depth than that of divisions No. 1 and No. 2. It is here that the best alfalfa, beets, and head corns have been raised, while on the other hand the same crops have been complete failures upon the same land. The soil is heavy and capable of producing good crops under a proper system of irrigation, but handled as a great deal of it has been it becomes a marsh. The soil does not drain naturally, and the large amounts of water that have been applied have literally submerged it until now some of it is bare of vegetation. The general fall is amply sufficient for a good system of underdrainage, and when such drainage is provided and intelligent care exercised in future applications of water it will make the most productive section under this system.

The area irrigated and the water used in this division is shown by the following table:

Acreage of crops and water delivered for the year ended October 1, 1899, division No. 2, Pecos Irrigation and Improvement Company—Continued.

Name.	Location.	Soil.	Acreage of crops. Alfalfa.	Corn.	Beets.	Cane.	Orchard.	Vines.	Garden.	Beans.	Trees.	Total.	Water delivered. March.	April.	May.	June.	July.	August.	September.	Total.	Depth of irrigation.	Remarks.
													Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Feet.*	
Mihlferd, John	NW. ¼ SW. ¼ NW. ¼ sec. 35, T. 22, R. 27 E.	Adobe		5		4						9			2.39	2.49	4.78	8.58		18.24	2.02	Good crops.
Mullane, W. H.	NE. ¼ NE. ¼ sec. 33, T. 22, R. 27 E.	do	1	2	4		1					8			6.52	12.14	3.84	2.56	15.04	40.10	5.01	Failure.
Rarey, J. F.	E. ½ NE. ¼ and NE. ¼ SE. ¼ sec. 28, T. 22, R. 27 E.	do	15	105		14	5					139	19.03	69.33	43.52	87.93	86.76	143.76	132.14	582.47	4.19	Alfalfa poor; corn fair.
Do.	S. ½ SW. ¼ sec. 22, T. 22, R. 27 E.	do	10	70								80	32.90		69.23	89.12		38.72	21.71	251.68	3.14	Do.
Scoggins, Ed.	SW. ¼ NE. ¼ sec. 35, T. 22, R. 27 E.	do	3	28		4						35		17.51	13.20	17.72	29.40	57.09		134.92	3.85	Good corn.
Stokes, J. W.	SW. ¼ SE. ¼ sec. 21, T. 22, R. 27 E.	Sandy	25	20		2	12					59		23.59	46.73	14.79	11.61	22.76	46.10	165.58	2.80	Good corn and alfalfa.
Tedford, Jack	NW. ¼ SE. ¼ sec. 27, T. 22, R. 27 E.	do		40								40		42.24	8.53			34.73		85.50	2.13	Good corn.
Foome, J. B.	SW. ¼ NW. ¼ sec. 34, T. 22, R. 27 E.	Adobe	25	11					2			38	38.61	6.41	37.68	16.03	38.59	65.54	44.54	247.40	6.51	Fair corn.
Tracy, F. G.	SW. ¼ SE. ¼ sec. 10, T. 22, R. 27 E.	Sandy	14	20	20	5	17		1			77		43.96	44.39	54.02	22.45	50.08	20.35	235.25	3.05	Fair crop; heavy peach crop.
Webster, G. H.	Sec. 21, T. 22, R. 27 E.	Adobe	208	75				30	2			315	106.51	364.70	259.39	37.84	95.35	186.86	140.82	1,191.47	3.78	Alfalfa fair (new seeding); corn good.
Wilson, W. A.	SE. ¼ SE. ¼ sec. 26, T. 22, R. 27 E.	do	20	7		10						37		5.39	19.29	9.05	10.36	36.61	22.81	108.01	2.78	Corn fair; alfalfa new seeding.
Wilson, W. B.	SW. ¼ SE. ¼ sec. 26, T. 22, R. 27 E.	do	30	8	3		3					44	.79	.69	14.50	28.05	11.40	7.48	16.48	79.39	1.80	Corn fair; alfalfa pastured.
Wright, C. H.	NW. ¼ NW. ¼ sec. 27, T. 22, R. 27 E.	do	5	7			5					17	17.41	.02	12.72	8.71	13.29	32.83		84.98	4.99	
Wright, C. W.	do	do	5									5	6.23			10.67	.18	9.69	6.38	33.15	6.63	Good alfalfa.
Yturaldi, S. A.	S. ½ NE. ¼ and N. ½ SW. ¼, sec. 1, T. 23, R. 27 E.	do	50	35						10		95		67.29	62.61	49.62	18.32	107.85	157.57	463.26	4.87	Poor alfalfa; good corn and beans.
Total			1,286	504	27	94	45	30	5	44	5	2,130	913.58	1,296.24	1,521.73	1,328.84	1,139.27	1,672.86	1,579.36	9,651.88	4.53	

DIVISION NO. 3.

This is a division of the greatest successes and worst failures. The soil is a heavy clay loam and has a greater depth than that of divisions No. 1 and No. 2. It is here that the best alfalfa, beets, and head corns have been raised, while on the other hand the same crops have been complete failures upon the same land. The soil is heavy and capable of producing good crops under a proper system of irrigation, but handled as a great deal of it has been it becomes a marsh. The soil does not drain naturally, and the large amounts of water that have been applied have literally submerged it until now some of it is bare of vegetation. The general fall is amply sufficient for a good system of underdrainage, and when such drainage is provided and intelligent care exercised in future applications of water it will make the most productive section under this system.

The area irrigated and the water used in this division is shown by the following table:

Acreage of crops and water delivered for the year ended October 1, 1899, division No. 3, Pecos Irrigation and Improvement Company.

[Yield, where given, estimated.]

Name.	Location.	Soil.	Acreage of crops.										Water delivered.									Remarks.
			Alfalfa.	Corn.	Beets.	Cane.	Orchard.	Vines.	Garden.	Beans.	Trees.	Total.	March.	April.	May.	June.	July.	August.	September.	Total.	Depth of irrigation.	
													Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Ft.*	
Abalos, B	SW. ¼ sec. 18, T. 23, R. 28.	Adobe	15	80	30	4			1			130		72.43	96.61	39.05	58.33	51.23	20.71	338.36	2.60	Failure; land subbed.
Anderson, W. W.	SW. ¼ NE. ¼ sec. 22, T. 23, R. 28.	Sandy	15	10	10							35		54.07	22.07	33.52	2.71	31.44	4.03	147.84	4.22	Failure.
Becerra, S. P.	NW. ¼ NE. ¼ and SW. ¼ NE. ¼ sec. 17, T. 23, R. 28.	Adobe	2	15	10	5			1	10		43			13.95	20.99	88.93	40.31	23.19	187.37	4.35	Failure: Mexican cultivator.
Benson, R. S.	Sec. 7, T. 23, R. 28.	do	520	80			20	5	1			626	72.07	337.80	328.61	243.92	127.85	203.77	164.86	1,478.88	2.38	Alfalfa yield 4 tons.
Do.	N. ½ NW. ¼ sec. 21, T. 23, R. 28.	do				80						80		37.77		1.06	62.07	31.28		132.16	1.65	
Bustamante, M.	SW. ¼ NE. ¼ sec. 12, T. 23, R. 27.	do			12				1			13				9.94		11.18	5.21	26.33	2.02	Beets yield 6 tons.
Calvani, T.	N. ½ SW. ¼ sec. 15, T. 23, R. 28.	Sandy	6	18	19	6			1	3		53	51.77	67.89	37.95	25.55	36.41	12.25	25.46	257.31	4.85	Fair crop.
Corrales, P.	N. ½ SE. ¼ sec. 17, T. 23, R. 28.	Adobe	12	11	40				1	2		69	5.72	66.87	41.55	41.55	41.68	37.00	25.49	259.86	3.76	Fair corn crop; beets a failure.
Dishman, C.	SE. ¼ NE. ¼ SW. ¼ sec. 21, T. 23, R. 28.	do		9					1			10			11.12	8.39	9.18	12.18		41.17	4.11	Corn yield 40 bushels.
Dearsley, Dick	NW. ¼ sec. 12, T. 23, R. 27.	do	22	60	31	3			1		2	119	39.74	17.87	26.21	63.02	30.49	66.16	63.10	306.59	2.52	
Dunaway, J. F.	SW. ¼ sec. 16, T. 23, R. 28.	Sandy	50	20	30				1	5		106	23.99	81.67	98.81	89.24	100.64	15.02	76.84	481.21	4.54	Corn good; alfalfa pastured; beets yield 4.5 tons.
Galton, W. W.	SW. ¼ SW. ¼ sec. 6, T. 23, R. 28.	do	35	3		5	1					44	9.91	12.91	15.08	27.96	21.43	30.40		117.69	2.67	Cane good; alfalfa yield 4 tons.
Garza, E. (Bolles)	N. ½ and NW. ¼ sec. 20, T. 23, R. 28.	Adobe	24	218	150					20		412	5.86	147.20	123.57	159.82	157.30	158.56	72.86	825.18	2.00	Failure.
Do.	N. ½ NW. ¼ and SE. ¼ NW. ¼ sec. 18, T. 23, R. 28.	do	35	12	40	3						90	23.81	65.90	27.29	99.92	19.67	29.28	44.75	310.62	3.45	Do.
Gomes, C.	S. ½ SE. ¼ sec. 17, T. 23, R. 28.	do	33	6	33				1			73	23.33	53.87	10.78	29.44	33.95	40.98	9.82	201.67	2.76	Alfalfa poor; beets yield 6 tons.
Grandi, A.	SE. ¼ sec. 1, T. 23, R. 27.	do	20	12	35	3			1	2		78	6.99	73.55	64.20	40.17	18.82	54.96	14.75	282.94	3.87	Beets poor; corn yield 30 bushels.

Gray, E. McQ	SE. ¼ NE. ¼ and NE. ¼ SE. ¼ sec. 29, T 23, R 28.	...do	23	15			40				21	[redacted]		83.53	33.20	26.69	29.86	58.57	21.01	202.79	2.53	Good crops.
Hughes, S	E. ½ and SW. ¼ NE. ¼ sec 25, T 23, R 28	...do	28	13	32	2	3			1		79	12.66	61.29	41.74	62.06	42.00	5.89	24.26	239.89	2.27	Poor crops; Mexican farming.
Krull, A	S. SE. ¼ and SE. ¼ NE. ¼ sec 10, T 23 R 27.	...do	70	45		2						117	47.01	99.79	98.06	55.76	66.48	82.47	15.06	464 67	3.97	Fair crops.
Louis, G	SW ¼ NW ¼ sec 8, T. 23, R 28.	...do		5	30					2		[redacted]			32.00	21.61	12.07	25.50	16.33	107.51	2.90	Beets a failure.
Lockhart, J H	N ½ SE ¼ SW ¼ sec 19, T 23, R. 28.	...do				8						8					6.50	10.89	8.15	25.54	2.19	Cane good.
McLendon, W	SW ¼ NE. ¼ sec 15 T 23, R. 28.	Sandy		25		2						27		16.17	30.94	13.12	34.17	1.14		95.54	3.53	Corn good.
Molino, A	SW. ¼ SE. ¼ sec 12, T. 23, R. 27.	Adobe			25				1	8		34			61.56	35.75	27.49	44.41	14.22	183.43	5.39	Beets yield 5 tons.
Niemeyer, F. H	NE. ¼ SE. ¼ sec. 24, T. 23, R. 27.	Sandy	8	5	6	1	2					22	1.08	6.40	14.65	3.26	2.73	8.85	3.10	40.02	1.81	Corn good; land subbed.
Nolty, Chris	NW. ¼ NW ¼ and SW ¼ SE. ¼ sec. 15, T 23, R. 28.	...do	15	27	9					1		52		56.96	32.21	53.97	10.47	34.95	27.23	194.79	3.74	
Nymoyer, J. O	SE. ¼ sec. 20, T 23, R. 28.	Adobe		40	40							80		11.15	27.04	51.87	21.75	62.14	42.29	216.24	2.70	Corn good.
Onsures, F	E. ½ SE. ¼ sec. 12, T. 23, R. 27.	...do			70				1	6		77			6.24	54.38	25.89	61.49		148.00	1.89	Beets yield 6 tons.
Ocon, C.	NW. ¼ SE. ¼ sec. 21 and NW ¼ SW. ¼ sec 22, T. 23, R 28.	Sandy	5	25	40	7			1	2		80		21.05	25.38	70.27	56.70	44.97	30.16	248.53	3.11	Corn fair; beets light.
Pompa, F.	N ½ SW. ¼ and SE. ¼ NW ¼ sec. 6, T 23, R 28.	...do	20	50	41	2						103	8.25	43.42	56.82	77.12	59.37	34.59	49.47	329.04	3.18	Corn fair.
P. V. B. S. Co.	NE ¼ sec 29, T 23, R 28	...do			145							145			79.00	109.09	99.14	66.12	261.86	615.21	4.24	Beets light.
Rascoe, J. J	Sections 10, 11, and 13, T 23, R 27	Adobe	425	235	252	65			4	20		1,011	238.25	200.71	492.85	471.40	495.94	486.09	290.43	2,675.67	2.64	Alfalfa yield 4 tons.
Ramus, A.	S ½ NW ¼ sec 15, T 23, R 28.	Sandy	25	30	12		2		1	1		71	4.39	80.24	71.31	42.57	18.82	75.85	8.37	301 55	4.27	Alfalfa nearly all pastured; beets and corn light.
Roark, S.	S. ½ NW. ¼ sec. 22, T. 23, R. 28.	...do	15	54		4				1		74	27.00	47 82	84.96	41.48	20.30	74.97	17.35	263.88	3.56	Alfalfa pastured; cane good; corn yield 40 bushels.
Salgado, B.	SW. ¼ SW. ¼ and SW. ¼ NW ¼ sec 8, T. 23, R. 28.	Adobe		13	47				1	5		66		14 38	14.96	74.70	54.94	67.15	34.90	261.03	3.96	Failure; no cultivation; land subbed.
Sillem, P. O.	E. ½ SE. ¼ sec 11, T. 23, R. 27.	...do	20	5	15	15	12					67	34.48	9.04	25.22	29.40	38.87	24.87	29.57	191.45	2.85	Failure; land badly subbed.
Singleton, Mrs. J.	SE. ¼ SW. ¼ sec. 1, T. 23, R 27.	Sandy		7								7				7.50	10.56			18.06	2.57	Corn good.

with return water from irrigated land under both the Salt and Gila rivers, in addition to the seepage water of the Agua Frio. This gives them a minimum supply of about 150 cubic feet per second (6,000 miner's inches) during the lowest stages of the river. The canal covers approximately 25,000 acres of land, only a small portion of which is yet under cultivation. The head works are located some 22 miles west of Phœnix.

The Mesa Canal, on which the observations of the duty of water in 1899 were made, was constructed and is maintained by a corporation of farmers whose land it irrigates. The stock of the canal is divided into 400 shares of a present value of $500 each. The annual cost per share is approximately $16, which, considering the excellence of their water system, is very reasonable. Their water supply is variable, depending on the stage of water in the river. This irregularity of supply is an unfortunate condition which can not be changed without a reservoir to impound flood waters. Under the present conditions the canals take all the water possible during floods and every user of water endeavors to spread his quota over as large an area as the limited time will allow. The result of this haste on the part of both the canal company and the farmer is generally a great waste of water, and the country roads after such a spurt are at times almost impassable. Again at a period of extreme low water the quantity in the canal is so small that the farmers in most cases simply use it for stock water and to irrigate such fruit or trees as they may have.

Observations of the duty of water under such conditions can not be considered as measuring the possible duty under the economical distribution which would be possible if storage reservoirs for floods were provided.

DIVISION OF THE WATER OF SALT RIVER AMONG CANALS.

The law controlling water distribution in the valley is known as the "Kibbey decision," which was rendered by Judge Joseph H. Kibbey in the year 1890, after long and tedious litigation. The fundamental principle of the decision is that the priority of actual application of the water to the land gives priority of right. This necessitated the determining of the date when water was actually applied on each and every parcel of land under the various canals named in the suit. The evidence thus deduced filled some 6,000 pages of type-written matter, and from it, under the direction of the court, was compiled a table showing the number of quarter sections irrigated in each year under each canal entitled to water from Salt River as per decree of court. The land area unit used in this table was one quarter section (160 acres). The duty of water as tentatively fixed was 64 miner's inches to the quarter section; the miner's inch being estimated as one-fortieth of a cubic foot per second. In the application of the Kibbey decision the above duty of water is not continually allowed to the lands having early

rights to the exclusion of all others, the land and canal owners having for the most part pursued a "live and let live" policy, which has permitted of a development that could not otherwise have been effected. It is evident, however, that there is a limit to which this latter policy should be pursued.

There are periods of low water in summer when a duty of 64 inches per one quarter section would allow water to but 35,000 acres of land, a tract much smaller than the 82,640 acres given adjudicated rights for the year 1884. The table prepared as a result of the Kibbey decision is as follows:

Table showing for each year the number of quarter sections under each canal entitled to water from Salt River as per Kibbey decision.

Year.	Salt River Valley Canal.	Maricopa Canal.	Tempe Canal.	San Francisco or Wormser Canal.	Utah Canal.	Mesa Canal.	Grand Canal.	Arizona Canal.	Total number of quarter sections for each year.
1868	12.5	1	....	....	....	....	....	....	13.5
1869	22	6	....	....	....	....	....	....	28
1870	31.5	14.5	....	....	....	....	....	....	46
1871	48	24.5	5	8	....	....	....	....	85.2
1872	78.5	28.5	49	8	....	....	....	....	167
1873	90.5	29	57	12	....	....	....	....	188.5
1874	90.5	31	57	12	....	....	....	....	190.5
1875	90.5	32	57	12	....	....	....	....	191.5
1876	92.5	36	57	12	....	....	....	....	197.5
1877	95.5	41	57	22	7	....	....	....	222.5
1878	102	53	67	22	24	23	2	....	293
1879	104	65.5	70	22	24	30	15	....	330.5
1880	109	81.5	70	21	24	35	17.5	....	364
1881	116.5	102	72	24	24	43	18.5	....	400
1882	117.5	117.5	90	27	26	50	23.5	....	451.5
1883	118.5	121.5	90	28	38	59	43.5	....	501.5
1884	119.5	128.5	95	28	38	62	45.5	....	516.5
1885	120.5	133	98	28	38	73	46.5	43.5	580.5
1886	121.5	135	105	29	38	75	47.5	105.25	656.25
1887	122.5	134	113	31	40	82	47.5	192.75	765.75
1888	123.5	139	117	31	55	82	48.5	333.25	929.25
1889	123.5	139	117	31	55	82	48.5	350	946

With the above table as a guide, the court, through its officer, a duly appointed water commissioner, apportions the water among the canals entitled to receive it during the various stages of medium and low water. At periods of high water every canal carries as much as it can take in at its head.

Mr. Trott, the present water commissioner, has his office in Phœnix, making periodical trips over the various canals in the valley, in order that he may keep constantly informed of the quantity of water being delivered in each. He is allowed one assistant, a gage observer, who reads the gages in the various canals twice a day, reporting the readings after each trip to Mr. Trott by telephone. The latter then makes his calculations, and as he has telephone connections which enable him to reach the headgates of all the canals on short notice, he can have them regulated as he desires at any time. His responsibility ceases when he has apportioned the water to the various canals. After the

water passes his gages it is handled by the canal company's zanjero, or water master, who distributes it to the different laterals under the system.

The water commissioner keeps a record of the water flowing in the canals under his jurisdiction, and at the end of the year compiles a table showing the amount received by each canal for each day of the year, also the monthly and yearly averages. The following table gives the average flow for each month of the year 1897 and the average for the year. The flow is given in miner's inches for local convenience, the inch, as before stated, being estimated at one-fortieth of a second-foot. This table is merely the summing up of the numerous pages giving the daily flow for each canal for the entire year. The Indians on the Maricopa Reservation are allowed a constant head of approximately 500 inches from Salt River, which is not included in the table.

Average flow of canals receiving water from the Salt River for the year 1897.

Month	South side.				North side.		Total water diverted.
	Tempe, San Francisco, Broadway	Mesa, Crismon, Consolidated.	Utah	Highland.	Arizona.	Joint-head.	
	Miner's inches.	*Miner's inches*	*Miner's inches.*	*Miner's inches.*	*Miner's inches.*	*Miner's inches*	*Miner's inches.*
January	4,443	5,475	1,604	458	4,897	2,694	19,571
February	7,094	9,406	3,908	1,220	17,930	4,643	44,201
March	11,199	9,901	5,008	1,436	23,448	7,417	58,409
April	10,568	9,105	2,565	1,212	21,501	10,347	55,298
May	9,672	9,692	4,054	300	18,425	7,320	49,463
June	6,944	1,942	1,697	....	7,430	3,394	20,407
July	4,138	766	797	....	3,082	2,759	11,542
August	6,382	3,350	2,302	....	10,919	3,078	26,031
September	8,199	7,193	3,412	427	12,390	5,630	37,251
October	7,433	5,463	3,049	90	8,045	4,808	28,888
November	3,776	2,115	2,421	....	10,617	3,210	22,139
December	6,362	3,091	1,341	....	8,560	3,289	22,643
Average flow for the year.	7,100	5,600	2,672	422	12,218	4,874	32,886

The court's authority at present does not extend outside of this valley, and it is beginning to be felt that the law of priority needs to be exercised beyond these limits. Under the present method of operation there is no way of guarding the priority of rights of the Salt River Valley to the waters of the Upper Salt and Verde rivers. Any man who can raise the necessary funds to build a ditch and dam on either of these tributaries can do so, take what water he wants, establish a home, and acquire possessory rights, while the people in the valley are in ignorance of the entire matter. This is the case in the other parts of the Territory also.

In Wyoming and other States having special irrigation laws no man or company can thus appropriate water without permission of the State engineer, and this permission is not granted if the stream is already fully appropriated. If a permit is given, the whole transaction is recorded, giving size of ditch, capacity, location, date of

appropriation, etc., so that there is no future trouble in adjudicatin the rights of the ditch or canal. This system eliminates for the mo part all the difficulties that would otherwise arise in endeavoring t adjudicate the claims of one county against another which was usin water from the same stream or its tributaries.

METHOD OF DISTRIBUTION UNDER MESA CANAL.

As before stated, the Mesa Canal Company receives its supply at th division gates of the Consolidated Canal Company. Their zanjero, o water master, then assumes charge of it, turning the water out to th laterals in accordance with the number of shares each lateral repre sents. It is then taken charge of by the various water masters on th laterals, who control its distribution to the lands. The duties of th latter are simplified by the fact that, as a rule, they have but littl dividing to do. The users of water under the laterals operate on th hour system, each share owned by any farmer entitling him to so man hours' run of the entire flow of the ditch. This rotation in use is th best and most economical method of distribution which they coul adopt under present conditions.

DUTY OF WATER UNDER MESA CANAL FOR THE YEARS 1896 1897, AND 1898.

The total area irrigated under the Mesa Canal approximates 12,00 acres of land especially well adapted to the growth of fruit and vege tables, as well as the more staple crops of grain, sorghum, alfalfa, etc (Pls. XXXII and XXXIII.) This area is not all under a high stat of cultivation, a considerable portion of it being farmed only for grai crops during the winter. These crops, being diversified, require dif ferent quantities of water, and such water at different seasons of th year. Grain is usually put in during October and November, and i irrigated periodically until the following May. Alfalfa is also irri gated more extensively during this season, though this is simply o account of the larger water supply. Fruit requires more water in th spring and summer months.

The tables show the flow in Mesa Canal for the years 1896, 1897 and 1898. It will be seen by observing the column of mean flow tha the season of high water is between the months of January and May This is invariably the rule, during which period immense volumes o water generally run to waste down the Salt River. At no place woul the great advantage of a reservoir as an equalizer of flow be bette appreciated than in this valley.

FIG. 1. DRYING APRICOTS IN ARIZONA.

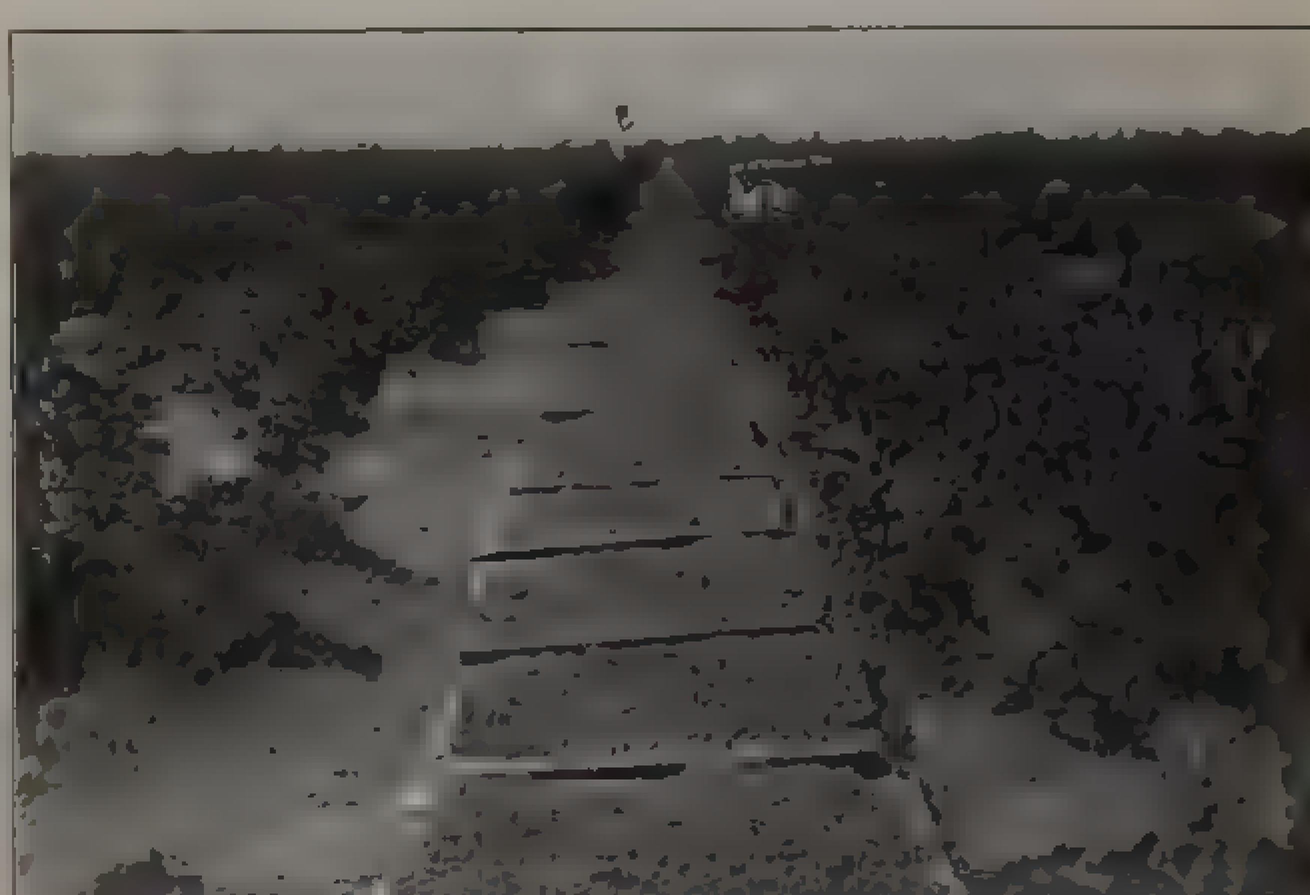


FIG. 2.—DRYING MUSCAT GRAPES IN ARIZONA.

FIG. 1.—VIEW OF A STOCK RANCH AT MESA, ARIZ.

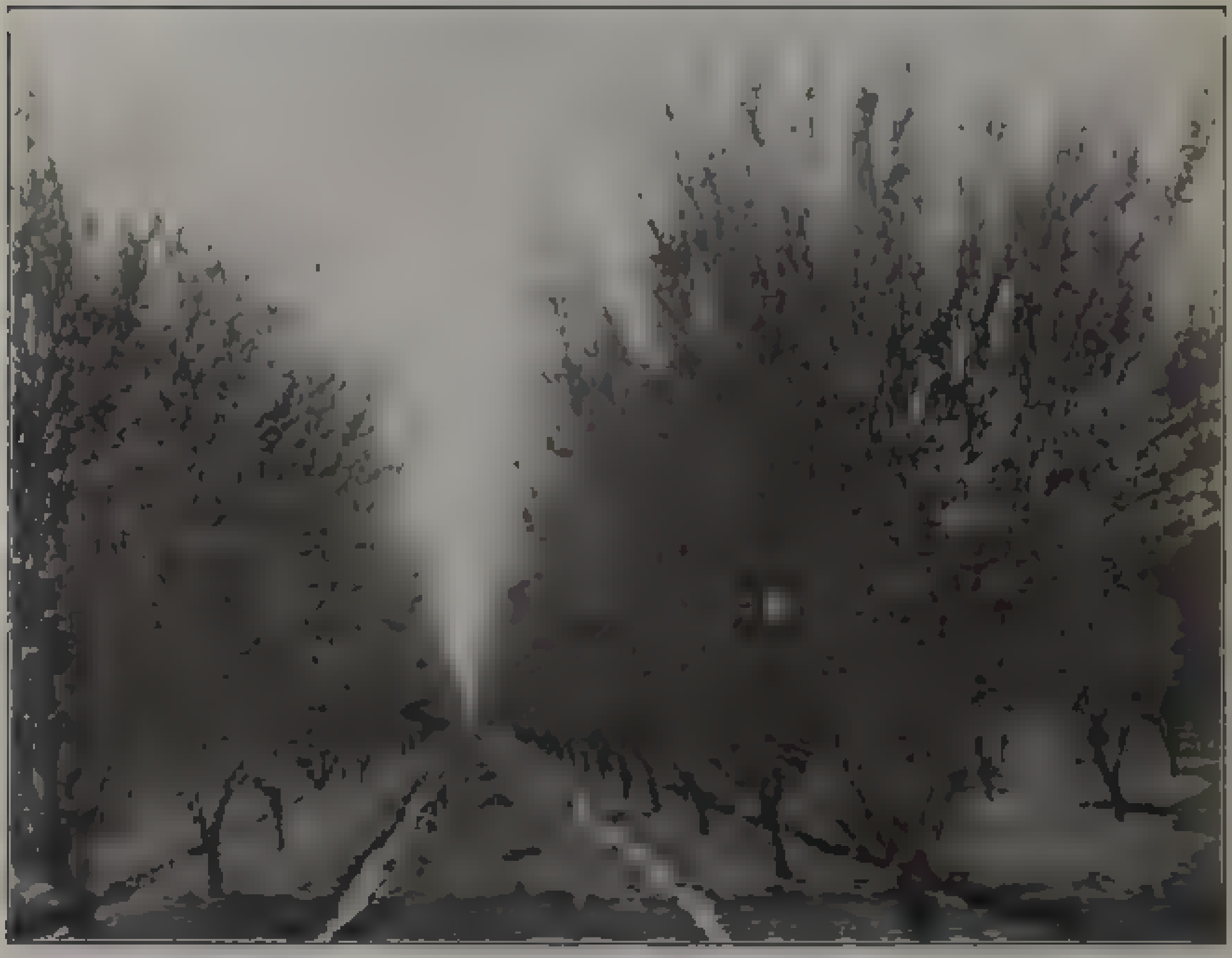


FIG. 2.—AN ALMOND ORCHARD IN ARIZONA.

Flow of Mesa Canal for the years 1896, 1897, and 1898.

Month.	Maximum.	Minimum.	Mean.	Total	Rainfall.
	Cubic feet per second.	*Cubic feet per second.*	*Cubic feet per second.*	*Acre-feet.*	*Inches.*
1896.					
January	175.0	75.0	117.25	7,209.4	0.15
February	132.5	18.75	79.06	4,547.0	.05
March	175.0	102.5	159.11	9,783.2	.46
April	210.25	117.05	165.50	9,848.0	.08
May	128.75	34.9	70.0	4,304.0	....
June	34.9	12.0	20.9	1,243.6	....
July	200.0	9.95	88.64	5,450.2	4.40
August	175.0	52.475	118.8	7,304.0	.26
September	175.0	54.425	107.31	6,385.8	.37
October	213.55	64.725	95.29	5,859.1	2.19
November	214.75	63.10	73.59	4,378.6	.85
December	115.3	50.8	76.57	4,706.0	.65
Total for the year	....	....	97.66	71,020.6	9.31
1897.					
January	150.0	56.6	76.10	4,750.4	2.67
February	169.55	150.0	159.62	8,864.8	.75
March	175.0	112.5	151.61	9,322.5	1.68
April	175.0	150.0	140.0	8,330.5	....
May	175.0	73.55	146.03	8,979.0	.16
June	90.7	16.75	42.02	2,500.3	1.00
July	41.875	4.4	15.21	935.2	.33
August	175.0	13.075	76.46	4,701.3	2.24
September	175.0	31.25	104.85	6,239.0	1.35
October	175.0	12.125	87.01	5,350.0	1.10
November	65.375	8.5	45.78	2,724.0	....
December	84.475	43.625	65.74	4,042.1	.30
Total for the year	....	....	92.56	66,739.1	12.58
1898.					
January	194.3	66.7	114.02	7,010.8	1.05
February	175.0	108.25	162.20	9,008.1	....
March	200.0	84.7	145.31	8,934.7	.44
April	194.9	90.25	138.0	8,211.5	.10
May	121.3	18.15	61.73	3,795.6	....
June	62.45	10.35	22.82	1,357.8	.12
July	175.0	8.025	93.46	5,746.6	.95
August	207.5	24.25	80.14	4,927.6	1.10
September	175.0	16.825	58.24	3,465.7	....
October	37.425	15.0	17.60	1,082.1	....
November	62.675	23.55	32.37	1,926.1	.70
December	175.0	40.0	84.76	5,211.7	2.39
Total for the year	....	....	84.22	60,678.3	6.85

The area irrigated under the canal in each of these three years is estimated at 12,000 acres. Upon that basis the preceding tables show the following duty of water:

Duty of water under Mesa Canal, 1896, 1897, 1898.

	1896.	1897.	1898.
Area irrigated .... acres..	12,000	12,000	12,000
Discharge of canal .... acre-feet..	71,020	66,739	60,678
Discharge per acre irrigated	5.91	5.55	5.01
Estimated loss from waste, seepage, and evaporation, 30 per cent......	1.77	1.66	1.50
Depth of irrigation .... feet..	4.14	3.89	3.51
Rainfall .... do...	.78	1.04	.57
Total depth of water received by land .... do...	4.92	4.93	4.08
Acres served by a continuous flow of 1 cubic foot per second[1]	123	130	145
Acres served by a continuous flow of 1 miner's inch[1]	3.07	3.25	3.62

[1] For 365 days.

The results shown in the above table would be very satisfactory if the 12,000 acres were in a constant state of high cultivation, producing maximum crops at all periods. This is not the case, however, as but little water is used on alfalfa during low stages of the river, and the farmer thus loses from one to two crops that could be easily grown had he sufficient water during the summer season. This same state of affairs exists throughout the valley generally, but the great productiveness of the soil, in response to the few extra irrigations afforded by reason of our occasional summer floods, makes the showing far better than in many places where the water supply is more abundant. It is fair to assume that could the present annual discharge of the canal be evenly distributed throughout the different months of the year and be delivered in uniform heads under a system whereby the farmer would be obliged to practice economical irrigation, its duty would not only be increased, but maximum crops would be insured.

I have estimated the loss from percolation, evaporation, and waste to be fully 30 per cent of the amount shown at the gage. This seems very high, but in the opinion of the writer it is a fair estimate considering the degree of heat experienced during the summer months, the wasteful methods of irrigation practiced during periods of high water, and the great waste caused by furnishing water to stock during low stages of the river. Judge Kibbey, in his decision, expressed himself very forcibly on this latter practice. The following is an extract from his decision:

> No man has a right to waste a drop of water. Any excess of water that he diverts and wastes by carelessness, negligence, or ignorance of economic methods of cultivation or irrigation, or failure to adopt them, he unlawfully diverts.
>
> It appears from the evidence in this case that large quantities of water are allowed to flow in the various canals and ditches to supply stock with water. This necessarily involves a great waste of water. At a small estimate I should think the evidence discloses an amount of water wasted thus sufficient, if properly applied to irrigation, to make productive 10,000 acres of land. The amount of water actually consumed by stock is insignificant. The loss is that due to evaporation and seepage in its long passage through the various canals and the miles of subsidiary ditches. This seems to me to be an unreasonable use of water. I do not mean to deny the right of the use of water for stock, for it has always been a recognized use, like that for domestic purposes, but it can not, I think, be diverted from its original course for that purpose. It has always been the law that stock and the public could drink from a water course, but not to impede its flow or diminish its quantity for that purpose. Instead, I consider the law to be, of bringing the water from a natural water course a long distance by means necessarily involving an enormous proportionate waste to water stock, the stock must be taken to the natural water course to drink or otherwise provided for. If the water be in the ditches on a man's ranch in the course of application directly to irrigation, it might be permitted to allow stock to drink from it, but it is an unreasonable use of it to permit water to be in the ditches for that purpose alone.

This states the situation very clearly, but unfortunately this portion of the Kibbey decision is not enforced. That it should be is the opin-

ion of all who have the best interests of the valley at heart. The cost of a well and pumping plant is not great, and each farmer should be supplied with one. The company with which the writer is connected furnished 1,000 head of stock with excellent water for several years with a well pump and horsepower that did not cost over $200. The lift was about 45 feet, but it only required four or five hours' work each day on the part of an inexpensive mule to keep the cattle well supplied with water even during the hottest weather. It is needless to say that the fresh water thus pumped daily was infinitely better for the cattle than that furnished from malaria-breeding mud tanks.

A few of our progressive farmers have put in windmills for stock purposes, and while the winds in this section are quite light, the results for the most part have been very satisfactory. Mons Ellingson, who has a cattle ranch several miles southwest of Mesa, states that he watered several hundred head of cattle by means of his windmill. A mill with horsepower attachment would perhaps be more desirable for those who could afford the outlay. The average monthly velocity of the wind, according to the records of the weather observer in Phœnix, will not exceed 5 miles per hour at a height of 57 feet above the ground; it would perhaps be higher on farms and ranches that present a considerable unobstructed area. It is essential to have a good storage tank of some kind, in event of either windmill or horsepower. Dr. A. J. Chandler has an excellent tank and watering trough combined on one of his ranches south of Mesa; it consists of a 100-foot section of a semicircular redwood stave flume with ends in, banded every few feet with iron hoops, which connect to cross pieces of 4 by 4 timber. The trough is 6 feet across and holds about 10,000 gallons. Fifty or more head of cattle can drink at once from the tank. As it is always kept wet, the lumber will last indefinitely.

Judge Kibbey also referred to the loss due to seepage and evaporation in the many miles of canals and laterals. This is one of the greatest sources of waste we have to contend with, as each canal and lateral while carrying small heads loses an amount of water by seepage out of proportion to the amount carried. Thus the Mesa Canal has a wetted perimeter of 17 feet when carrying only 500 inches; when carrying 5,000 inches the perimeter or surface exposed to seepage will not exceed 22 feet. The Arizona Canal, with a bottom width of 30 feet, loses by seepage and evaporation approximately 30 inches per mile when carrying the ordinary summer supply, notwithstanding that it has an excellent cross section and is lined with a coating of silt that is almost impervious to water. This loss would be increased but very little with double the amount of water in the canal, and what is true in this instance of course holds good for smaller canals and laterals. The efficiency of the summer supply would be largely increased if the respective canal owners could enter into arrangements whereby

they might receive a larger supply of water for a shorter time by pursuing a system of rotation during stages of low water in the river.

OBSERVATIONS ON DUTY OF WATER IN 1899.

The observations as given above are close approximations for the years stated, but are more general in their character than those begun in 1899, under the direction of Professor Mead, irrigation expert in charge.

The purpose of the latter was to determine the actual volume of water used on a given area. Six thousand acres irrigated from the Mesa Canal was the area chosen. As canals vary in depth from day to day and sometimes from hour to hour, it was necessary to have a continuous record of the depth of water passing through the canal. This was secured by placing a self-recording register in the canal one-half mile below where its water supply is delivered by the Consolidated Canal. The instrument was started on April 2 of 1899, and accurately recorded the gauge readings from that date until October 1, the close of the observations for the year. It continues to record flow since that date, the data thus obtained to be used in future reports.

The following is the acreage of the different crops grown:

	Acres.
Alfalfa	4,102.00
Grain	806.50
Grain and alfalfa	443.75
Fruit, vineyards, orchards, etc	569.00
Vegetables	32.75
Total	5,954.00

In addition to the above acreage there were a number of trees, small lawns, and garden patches watered in the townsite of Mesa, which are not included in this report, but which would easily swell the total to 6,000 acres.

The amount of water for this tract that passed the rating station previous to putting in the register, according to daily records on file, was 10,032 acre-feet. The amount from April 2 to October 1, as per recording instrument, is tabulated as follows:

Discharge of Mesa Canal, January 1 to September 30, 1899.

[See diagram, Pl. VI, p. 72.]

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	72.2547	29.5917	28.1835	268.2975	39.0579
2	36.6876	73.3339	37.5967	23.2562	242.0081	40.5223
3	110.0446	74.7554	56.5421	20.3636	229.2942	33.1934
4	119.7696	60.2645	44.1736	23.5240	80.5983	28.3240
5	128.5091	65.0132	39.8314	21.8959	248.0149	21.5291
6	131.7355	64.5421	41.4744	24.4810	227.4149	19.5695
7	139.3202	56.3339	32.5240	22.1752	189.8628	124.9570
8	142.5769	54.7008	26.0050	21.7587	156.6215	235.1835
9	135.4661	55.3058	37.1818	25.7025	133.0149	187.7653
10	129.4475	49.3074	35.0099	32.7488	107.6397	135.8926
11	135.1851	32.4645	29.9934	47.6959	49.5058	62.2347
12	137.7620	40.8099	25.8347	57.2512	58.1488	41.0529
13	139.1405	54.3835	26.5008	104.7686	67.3554	53.4017
14	132.9769	45.0248	21.5902	62.6182	55.4017	45.7620
15	121.4876	35.5124	20.8050	58.5438	99.1851	32.3223
16	119.4612	37.9653	19.8909	57.6430	93.0810	24.4909
17	139.8066	34.5733	21.4083	75.8479	58.6264	25.7256
18	144.2496	35.2231	34.1636	95.9488	34.3025	20.6479
19	141.6446	27.5868	24.2975	103.3636	31.5653	20.0777
20	132.9488	30.8711	31.8843	114.2860	35.2678	26.4017
21	135.9074	38.4331	27.3669	75.1702	34.3521	27.6397
22	130.5306	35.2033	27.1721	133.0562	25.6661	26.3008
23	117.7124	37.3868	33.4479	153.0595	30.9256	30.4463
24	108.6628	36.4529	21.3521	147.3190	23.3256	32.2215
25	99.8446	32.5537	42.3273	119.6959	18.3669	32.6281
26	95.3388	32.7207	30.7471	152.8114	17.2760	31.1603
27	99.8298	31.9636	28.8182	98.8083	17.2760	33.1669
28	95.1355	36.6298	23.0413	141.1488	20.9603	32.4050
29	90.5570	35.2397	34.4463	233.1140	20.6678	33.3818
30	86.8760	42.9537	28.4182	240.5504	29.8926	25.6264
31	....	30.1818	....	253.0942	40.9769	....
Total	3,478.6149	1,389.9455	933.4367	2,769.8843	2,744.8925	1,523.0888

	Acre-feet.
Flow from January 1 to April 1 (from daily gauge readings)	10,032.0000
Flow from April 2 to September 30 (from register sheets)	12,839.8627
Total flow from January 1 to September 30, 1899	22,871.8627

The monthly precipitation at Mesa for the year 1899, as measured by the United States Weather Bureau, was as follows:

	Foot.		Foot.
January	0.11	July	0.11
February	.03	August	.03
March	T	September	.06
April	T		
May	.00		.40
June	.06		

The data given above show the following duty of water for 1899:

Duty of water under Mesa Canal, 1899.

Area irrigated ...acres..	6,000
Discharge of canal...acre-feet..	22,872
Discharge per acre irrigated...do...	3.81
Estimated loss from seepage, waste, and evaporation, 25 per cent ...foot..	.95
Depth of irrigation ...feet..	2.86
Depth of rainfall...do...	.40
Total depth of water received by land ...do...	3.26

It will be noted that the estimate of loss in the above table is but 25 per cent. This is because the rating station is several miles nearer the irrigated area than is the commissioner's gauge, from which the data previous to 1899 were obtained, the commissioner's gauge being about 8 miles from the center of the irrigated area.

The supply of water in Salt River for 1899 has been much below the average. Mr. Trott estimates that the combined daily flow in the canals of the valley for the present year to October 1 has been 10,000 miner's inches less than the average daily flow for the past five years, and the figures giving the daily flow show the variable water supply. The rainfall was also very small.

The total depth applied from January 1 to October 1 is 2.86 feet, and the yield from the 6,000 acres can be said to have been wholly produced by this amount of water plus the rainfall of 4.69 inches, although this does not include the entire year or the entire period in which water is used; but in a region where cultivation and production never end, and where there is no distinction between seedtime and harvest such as exists in Northern climates, there has to be some arbitrary point for beginning. The one chosen is as satisfactory as if it included the entire twelve months, because the value of the crops on January 1, when investigations began, did not differ largely from their value on October 1, when observations for this year closed, and in recording yields for the season just past the value of the crops on October 1 has not been taken into consideration.

The writer found it no easy task to obtain the acreage and yield of 6,000 acres of diversified crops. Many of the letters sent out were not answered, so that finally it became necessary to employ a canvasser, who personally interviewed all delinquents. This plan proved more expeditious and accurate, though more expensive.

The yields given can not be considered more than a close approximation, for the reason that few farmers keep a close record of their crops and pasturage.

Approximate yield from 6,000 acres under the Mesa Canal, January 1 to October 1, 1899.

Products.	Quantity.	Price.	Amount.
Alfalfa ....tons	3,207	$4 per ton	$12,828.00
Alfalfa seed ....pounds	27,650	$0.07 per pound	1,935.50
Barley ....do	375,900	$1 per cwt	3,759.00
Wheat ....do	437,275	...do	4,372.75
Apples ....do	4,900	$0.02 per pound	98.00
Apricots ....do	151,000	$0.01 per pound	1,510.00
Almonds ....do	41,500	$0.105 per pound	4,357.50
Grapes ....do	159,500	$0.01 per pound	1,595.00
Figs ....do	47,650	$0.02 per pound	953.00
Nectarines ....do	600	...do	12.00
Peaches ....do	82,400	$0.01 per pound	824.00
Pears ....do	33,000	$0.02 per pound	660.00
Plums ....do	600	...do	12.00
Prunus simoni ....do	23,700	$0.03 per pound	711.00
Quinces ....do	1,560	$0.02 per pound	31.20
Eggs (dealers' estimate) ....dozen	42,332	$0.17 per dozen	7,196.44
Poultry (shippers' estimate)			4,000.00
Honey (shippers' estimate)			3,000.00
Milk (cash paid by creameries)			8,480.00
Stock, pastured for eight months ....head	3,478	$0.75 per head per month	20,868.00
Total			77,203.39

In making up the above statement of yields we have endeavored to make a conservative estimate. As before stated, but few of the farmers kept books, most of them depending largely on memory for estimate of yield. There was also a suspicion among a few of the farmers that the assessor would in some manner obtain the data thus given and use it to their future disadvantage. On the whole, however, it is as close an estimate of yield as it is possible to obtain, and the error, if any, is in placing the yield too low.

The gross income per acre for the first eight months of 1899 according to this statement would be $12.87. This is not large, owing to the returns from the skillfully farmed lands being merged with those from lands that were poorly taken care of. The return from Mesa lands is in proportion to the labor and skill exercised in their cultivation, and in examining these statistics it was a common thing to find tracts that produced double the amounts of the adjoining farms. Almond, peach, pear, and apricot orchards, vineyards, and gardeners' tracts when well handled produced yields per acre varying from $20 to over $100, though there were also a number of small, ill-kept orchards that were not worthy of the name. It must be borne in mind that these returns are for but eight months of the year and that the lands in the Salt River Valley produce to a greater or less extent throughout the entire twelve months.

APPROXIMATE VALUE OF EACH ACRE-FOOT OF WATER APPLIED.

The actual cash cost per acre-foot.—In various irrigated States and Territories the relation between the acre-foot of water and its actual cash value when properly applied to land is one of the most important factors in estimating either the probable return from canals or the benefits to come from the construction of storage reservoirs.

To irrigate the 6,000 acres of Mesa land from January 1 to October 1, 1899, required 22,872 acre-feet of water. Dividing the latter amount into the total value of yield in dollars and cents ($77,203.39) gives $3.37 as the return from each acre-foot used. It is evident that with a regular supply of water, which could be furnished by the construction of storage reservoirs, the value of an acre-foot would be much higher.

Many of the farmers in giving their yields affirmed that their products would have been double if the same amount of water could have been delivered to them in uniform heads, according to the wants of the crops. This approximate gross value per acre-foot will give some idea of what a source of potential wealth to the Salt River Valley exists in the "Tonto Basin Reservoir."

In individual instances the return was much in excess of that above given for common diversified farming. The returns from the Trippell almond orchard gave over $30 per acre-foot applied, and in gardening and melon culture the value was even higher, though, unfortunately, tracts of land so utilized did not come under the field of this year's investigations. The returns from the orange orchards are not included in this report, since they are not on the market until late in November. This branch of horticulture on the Mesa lands being still in its infancy, the yield and the consequent profit from the same is not yet large, but orchardists are looking with confidence for a brighter future. The valley produces an excellent orange, and the fact that they can be sent to market several weeks earlier than other oranges, gives promise of a value per acre-foot for water far in excess of any product mentioned in this report.

APPROXIMATE COST OF WATER PER ACRE-FOOT.

The number of shares in the Mesa Canal represented on the 6,000 acres of land was 234. These shares have a par value of $250 each, and at present are selling at $500. Estimating the investment at the latter enhanced valuation, the cost per share for eight months, including interest, would be as follows:

Ten per cent on value of share	$33.32
Operating canal	12.00
Maintenance of laterals	4.00
Total cost	49.32

This gives a total charge for the 234 shares of $11,540.88, or a cost for the 22,872 acre-feet of 50 cents per acre-foot of water applied. This is reasonable, and is made so especially because of a favorable contract with the Consolidated Canal Company, whereby the Mesa farmers are relieved of the burden of maintaining an unstable dam and headgate.

DUTY OF WATER ON GRAIN FIELD AND YIELD FROM SAME.

A careful calculation was made of the water furnished certain land under a lateral supplied with a rating station. The farmer, Mr. John Vance, of Mesa, sowed 123 acres of barley and alfalfa together in November, 1898, sowing, approximately, 70 pounds of barley to the acre. He commenced irrigating November 20, 1898, rotating with other shareholders in his circuit, thus getting large streams for short periods. He finished his last irrigation on May 14, 1899, making a total irrigating season of 175 days.

The amount of water which his shares represented at the commissioner's gage would have covered his land to a depth of 2.82 feet. Estimating that 30 per cent of the water passing the gage was lost in seepage, evaporation, and waste, it leaves a total depth applied of 1.98 feet. In addition to this there was a rainfall during the period of 4.39 inches. The water was well handled and properly applied, and from the showing made there was evidently enough of it, though the farmer would probably have used more could he have obtained it.

The harvesting was finished early in June. His yield was 2,703 sacks of barley, averaging 95 pounds per sack, making a total of 256,785 pounds, or 2,087.68 pounds per acre. The value of barley at harvest time approximated 95 cents per hundred pounds, giving a return per acre of $19.83.

The farm was virgin soil, never having been irrigated before, unless it was by a prehistoric race. The soil is light alluvial and not considered by many farmers as being so well adapted to grain raising as the heavier soils in other sections of the Mesa country. The net profit, after allowing for wages and paying for all harvesting, will closely approximate $1,400, and in addition an excellent stand of alfalfa is on the ground.

The gross income from the above 123 acres was at the rate of $19.83 per acre, and this return was reaped in about six months. The amount of water used was 344.86 acre-feet, giving an approximate gross value of $7 per acre-foot applied. The difference in this value per acre-foot and the one previously given is more than 100 per cent, and illustrates the point before made that some lands produced double the amount of adjoining farms, for the simple reason that they were properly handled.

The above is a larger yield than is usually secured on virgin soil, but not so large as the average yield of grain sown on old alfalfa land, which frequently averages over 3,000 pounds per acre. The rainfall during this period was very light, necessitating more irrigation than would have been necessary if there had been the usual precipitation. There are instances when the rainfall has been sufficient to mature grain crops with the aid of one or two irrigations, but these instances are so rare that they are not to be counted upon. During seasons of

high water there are also many instances where the farmer, in anxiety to "soak up" while the water lasts, has nearly or quite rui his crops by an oversupply.

METHODS OF HANDLING WATER TO OBTAIN GREATEST EFFICIENCY.

As regards the best methods of handling water to increase its efficie on the crops above tabulated, the writer has tried to obtain the vi of practical and successful irrigators of experience in their vari lines.

FRUIT.

As regards horticulture (almonds), the following letter from J. E. Bettler, who has charge of the fine Trippell almond orch near Mesa (Pl. XXXIII, fig. 2, p. 116), is submitted:

MESA, ARIZ., *October 12, 189*

Mr. W. H. CODE.

DEAR SIR: In reply to your request, would state that I could only make an appr mate estimate of the amount of water used under the present system of distributi This system is made in the interest of the alfalfa and grain growers, consequently average of fifty per cent of water for orchards is lost. To obtain the best resu I would prefer to have water as follows: 120 inches 18 hours twice a month, or same amount 36 hours once a month. I use the furrow system in irrigation, allow just sufficient water to flow in each furrow so that there will be no w water. The smaller the flow the deeper the penetration into the soil, consequen less waste.

The short and frequent irrigations so commonly in vogue in this valley cause a of at least 50 per cent of the practical utility of the water, and, furthermore, m the orchards short lived. The condition of the soil is of much importance. Wh the furrows are made in hard and compact soil, water is of little value to the tr The ground should be well broken, so that the water can enter deeply into Following the furrow with a subsoiler would be beneficial.

From September to May irrigation should be followed by plowing or cultivati The most thorough irrigations are made in the winter, in order to use the land a reservoir to supplement the short supply in the river in May and June, also to k the roots from coming to the surface for moisture, and hold them deep in the grou and so avoid check growth. It is also beneficial in conjunction with "smudgin (the building of smoldering fires) for protection from frost, and is essential to success almond culture.

It would seem that winter irrigation is as essential to the production of cert kinds of fruit as it is to growing alfalfa. The owner of a Thompson Seedless gr vineyard near Mesa states that he depends largely on winter irrigation. He gi his vines two or three good waterings during this period, and in the spring and ea summer keeps the surface as moist as possible with his decreased water supply, cul vating thoroughly during the latter period.

It would be interesting to know to what depth these copious winter irrigatio saturate the soil. The general practice seems to be to fill the ground during t period, in this way providing a reservoir to tide over the months of limited suppl

GRAIN.

Mr. H. S. Phelps, a practical farmer of Mesa, has supplied the following description of his methods of irrigating grain:

> The ground should be irrigated thoroughly by the middle of October, then plowed; early in November irrigate it again thoroughly, and follow up as soon as possible with seeding, this in turn to be directly followed with peg-tooth harrow. Two subsequent irrigations will then make a fine grain crop.
>
> If there is alfalfa ground in addition to grain land, use the water provided by the ditches on it after the grain is sown, and allow it to soak in thoroughly; then when the time comes for irrigating grain, the alfalfa has had plenty of water to last it until the grain crop is taken care of.

Mr. Phelps states that by this irrigation the efficiency of water is largely increased, and that one water share in the Mesa Canal will irrigate in ordinary seasons 25 acres of grain and a like tract of alfalfa. This plan might be further improved by the use of a press drill seeder.

ALFALFA.

In irrigating alfalfa, the borders should be solidly built and from 4 to 6 rods apart, depending on the intervening fall of land and the head of water available. The head ditches should be from three-eighths to one-half mile apart, also depending on slope of country, and should be well constructed, having uniform cross section.

In irrigating, it is desirable, when possible, to turn good heads of water between each set of borders, so that the quantity may be sufficient to spread quickly and uniformly over the intervening area. It is a common condition for the "lands" to have poor and weak borders, so that the water which should be confined between them breaks through into adjoining lands, and a large portion is wasted in indiscriminate flooding. It is of course primarily important that the land should be well leveled, but the construction of substantial borders enables the farmer to force the water over irregularities in the surface that would otherwise receive no irrigation. This manner of confining the water is especially necessary in the summer season, since when the supply is limited it enables the irrigator to spread it over the surface more rapidly, moistens a greater area, and reduces the chances of scalding alfalfa to a minimum. Also during summer floods it enables farmers to push the water rapidly over the surface and prevents the heavy deposit of silt that would otherwise smother out closely cropped alfalfa.

PASTURES.

In collecting statistics of yields from the 6,000 acres, the canvasser obtained the average number of stock pastured each month from January 1 to October 1, 1899. One farmer, Mr. C. S. Steward, made the remarkable showing of pasturing an average of 450 head of cattle in

addition to cutting a crop of 310 tons of alfalfa from 240 acres of land. He states that in handling water to the best advantage in pasturing stock, it is advisable to have four or five pastures, so that one may, by changing cattle from one to another, irrigate continuously. In the winter and spring months he soaks his fields thoroughly, allowing the water to run continuously in small heads. If the water supply allows him a late spring irrigation, he can subsequently cut two crops of hay without further watering. He shifts his cattle from field to field while this irrigation is going on. After he begins haying he allows the cattle to follow behind, gleaning everything that is left. He states that the alfalfa is in no way injured by a very close cropping in dry weather. His subsequent summer supply of water (outside of flood periods) is pushed as rapidly as possible over the various fields to moisten the surface, which practice tends to retain the moisture underneath, and this tides over the intervals between more thorough irrigations. Mr. Steward could not have made such a record in pasturing cattle had he not been able to keep them all together. Had he been forced to divide them into several bunches, the showing would have been much smaller.

Mr. McQueen, who has charge of a ranch on which pure-bred Galloway cattle are grown (Pl. XXXIII, fig. 1, p. 116), says that in handling such cattle the showing in pasturage can not be made so great, owing to the necessity of keeping the stock separated in different fields, and that dividing the fields into pastures of 40 acres is the best plan, not only for the cattle, but in order to utilize a low water supply to best advantage.

There are other portions of the valley where a larger water supply gives extraordinary results in pasturage and alfalfa raising. This is notably the case on the lands under the Tempe Canal, which has one of the largest appropriations of water of any system in the valley.

CORN.

The writer is indebted to Mr. George Schornick, a successful corn raiser, for the following data:

Select good strong soil and flood it thoroughly about the middle of July. As soon as practicable, usually the first or second day subsequent to irrigation, begin operations with a combined lister and drill, running the same a depth of between 4 and 5 inches, and using Eastern corn for seed. Corn will come up in three or four days. When it is about 6 inches high, run a tooth harrow down each row, which will pulverize the surface of the ridges and rake or cultivate sufficient fine soil around the young corn for the first time. Then follow with an irrigation about twelve days from time of planting, running water down furrows between rows; follow irrigation with a two-horse cultivator, giving the corn a thorough cultivation, and throwing the dirt to the corn. Go through the same process every twelve days until the corn is too large to cultivate. It will be found that corn can be harrowed once and cultivated about three times before it is too large.

It will be noted that the time for seeding is about July 15, which allows corn to be taken care of during periods of low water. There were times when Mr. Schornick's supply was very limited indeed, but small as it was he always made some progress, owing to the plan of furrow irrigation, which greatly increases the efficiency of the water.

The methods of furrow or subirrigation should be followed whenever possible, not only on account of the great saving of water, but also for the more profitable yields assured. Even alfalfa grows better on top of the borders.

MELONS.

Mr. J. Holdren, of Mesa, has attained great success in growing the Georgia watermelon and the Rockyford canteloupe. He shipped the latter to many portions of the United States, including New York City.

The Mesa farmers have not entered into melon culture on the scale of the farmers in the vicinity of Phœnix, but the showing this year has been so satisfactory that their culture is likely to increase.

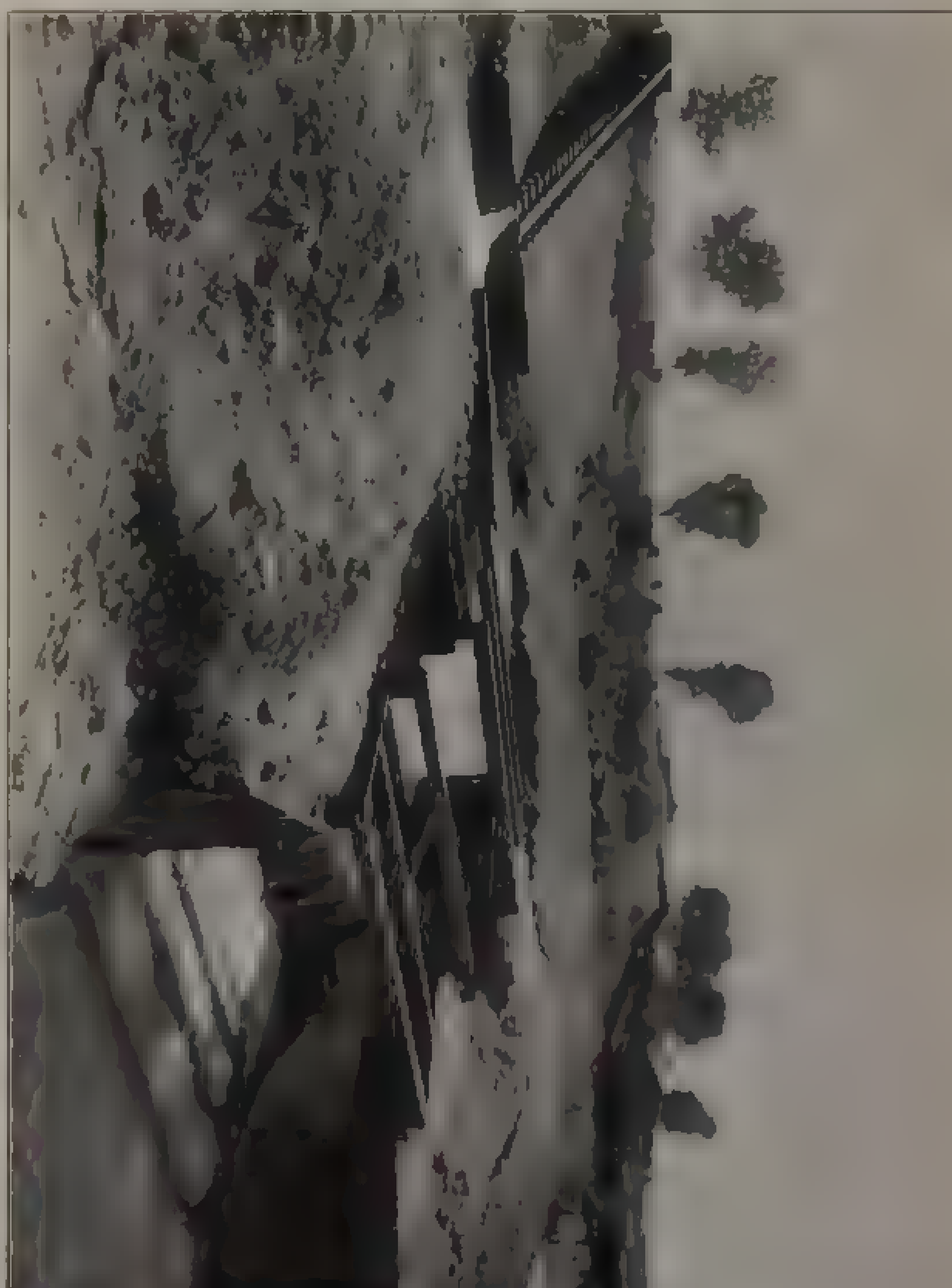
Mr. Holdren states that in gardening and melon culture the principal factor for economical irrigation is thorough cultivation at just the time when the soil is in proper condition. This latter knowledge can be gained only by experience, on account of the great variety of soils. He further states that careful preparation of the ground before planting is the foundation of success. Use the furrow method of irrigation, water every ten or twelve days until melons are growing, then every five or six days if possible, cultivate after each irrigation until vines cover the ground, and never flood the soil after planting.

For successful gardening and melon culture it is essential to use water according to the demands of the crop. Fortunately, owing to the system of furrow irrigation employed, it is possible to make considerable progress during "a turn," even in periods of low water, but the greatest difficulty is in obtaining the water with sufficient frequency during the summer months. Under some of the Mesa laterals, where there are a large number of shares, the "turns" are ten or twelve days apart during the low-water period, and crops often suffer between turns. It will be noted that Mr. Holdren recommends irrigating melons every five or six days, if possible, after they have reached a certain stage.

PUMPING WATER.

If the gardener could afford a small gasoline pumping plant, to provide a supplemental supply from wells, it would remove the element of uncertainty above mentioned. A pumping plant of this character could also be used to good advantage as a supplemental supply to

vineyards and for orange and almond orchards. There is an abundance of underground water in this vicinity which could be developed. The Consolidated Canal Company has a well at their power house (Pl. XXXIV) from which they pump 150 inches of water for irrigating purposes for lands in the vicinity. The well is 8 by 16 feet, horizontal cross section, and is 30 feet deep. Surface water was found at a depth of only 8 feet below ground level. This well is situated at the foot of the Mesa bluff, an exceptionally good location. On top of the bluff water is found at depths varying from 20 to 40 feet below the surface, depending on the location, fall of the country, and formation of the subsoils. If gravel, coarse sand, or quicksand are encountered when excavating a well, an exceptionally good flow can be calculated upon. A flow of 50 to 60 inches can be obtained by a small outlay, but when a discharge of 150 inches is desired the cost increases out of all proportion to the depth of the well, owing to the expense of keeping the water out of the way of the well diggers.



POWER HOUSE AND WASTEWAY OF THE CONSOLIDATED CANAL COMPANY, ARIZONA.

CALIFORNIA.

DUTY OF WATER UNDER GAGE CANAL, RIVERSIDE, CAL.

By Special Agent W. Irving, C. E.,
Chief Engineer Gage Canal.

LOCATION.

The Gage Canal system, including water sources, canals, and land capable of irrigation from said system, is situated in the counties of San Bernardino and Riverside.

The water supply is obtained from within the boundaries of the San Bernardino Rancho, comprising 2,831 acres, the lots and blocks of which rancho are shown on the accompanying map (Pl. XXXV). The Santa Ana River runs through the above-described property for a distance of about 4.25 miles, as measured along its channel.

The headgates of the Gage Canal (Pl. XXXVI, fig. 1) are located at a point on the south bank of the Santa Ana in lot 3, block 69, of the San Bernardino Rancho, or in sec. 13, T. 1 S., R. 4 W., San Bernardino base and meridian. From thence the canal runs generally in a southwesterly direction over the bottom lands of the Santa Ana Valley, a distance of about 2 miles; thence, skirting the sloping bench land for 1 mile, its channel is carried along the face of a high bluff by means of tunnels and trestle work until it emerges on the Riverside plains, across which it continues to its termination in the SE. ¼ sec. 19, T. 3 S., R. 5 W., San Bernardino meridian, a total distance from the place of beginning of 20.16 miles.

The lands capable of irrigation from the Gage Canal system, both below and above the height of the 100-foot contour, are particularly well fitted for the culture of citrus fruits. They are situated mainly in Riverside County, ranging from sec. 5, T. 2 S., R. 4 W., San Bernardino meridian, in San Bernardino County, to sec. 26, T. 3 S., R. 4 W., San Bernardino meridian, in Riverside County, comprising a total acreage of 11,469.08 acres.

WATER RIGHTS.

The form of water right prevailing in the valley of the Santa Ana is mainly that provided under the State laws, and is known and designated as "right by appropriation." This form of right, of course,

applies to the waters of natural streams, and is therefore subject limitation by the application of the law affecting riparian rights.

The sections of the civil code of California, under which rights appropriation can be acquired, read as follows:

SEC. 1410. The right to the use of running water flowing in a river or stream, down a canyon or ravine may be acquired by appropriation.

SEC. 1411. The appropriation must be for some useful and beneficial purpose, a when the appropriator, or his successor in interest, ceases to use it for such purpose the right ceases.

SEC. 1414. As between appropriators, the one first in time is the first in right.

SEC. 1415. A person desiring to appropriate water must post a notice, in writi in a conspicuous place at the point of intended diversion, stating therein:

I. That he claims the water flowing to the extent of (giving the number) inch measured under a 4-inch pressure.

II. The purposes for which he claims it and the place of intended use.

III. The means by which he intends to divert it and the size of the flume, dit pipe, or aqueduct in which he intends to divert it.

A copy of the notice must, within ten days after it is posted, be recorded in t office of the recorder of the county in which it is posted.

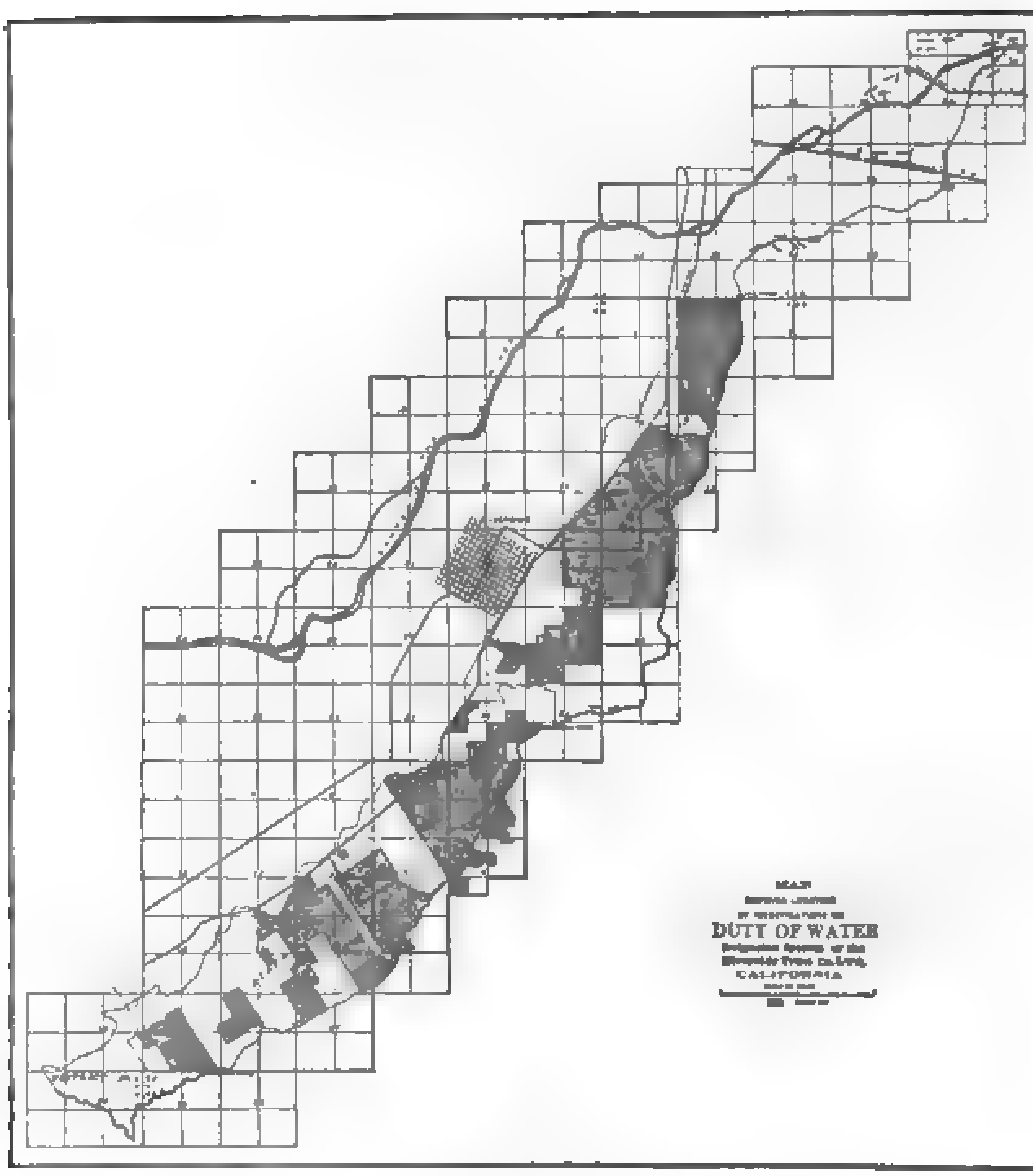
SEC. 1422. The rights of riparian proprietors are not affected by the provisions this title.

WATER SOURCES.

It may be taken without question that all the water used under t different irrigation systems in the Santa Ana Valley has its orig primarily in the San Bernardino Mountains, whether it is eventual diverted from surface-flowing streams or from subterranean channel The drainage from this range of mountains manifests itself in the va ley in three ways, namely: Surface-flowing streams direct from t canyons; subterranean waters coming to the surface in the form springs; and again by artificial springs created by means of artesia wells tapping the underground streams and thus developing a flow water from that source.

Upon these sources, then, the irrigation systems of the Santa An Valley depend for their supply of water, and the Gage Canal syste depends on all three, although at the present time most of the wat is received from artesian wells (Pl. XXXVII), now sixty-five i number, including three not yet fully completed.

The right of this canal to divert water from the Santa Ana is base on the claims of the following ditches which had established leg rights to do so: The "Hunt & Cooley" ditch had a right of diversio from the river at a point now occupied by the Gage Canal, and fro that point the water from the river was carried in a ditch to the lan south and below the flow of the canal as now constructed. This righ was transferred to the Gage Canal by an agreement entered int between the owners of the Hunt & Cooley ditch and Mr. M. Gage whereby the latter agreed to supply the above ditch with 130 inche



MAP OF THE IRRIGATION SYSTEM OF THE RIVERSIDE TRUST COMPANY, LIMITED, CALIFORNIA.

FIG. 1.—HEAD OF GAGE CANAL, CALIFORNIA.

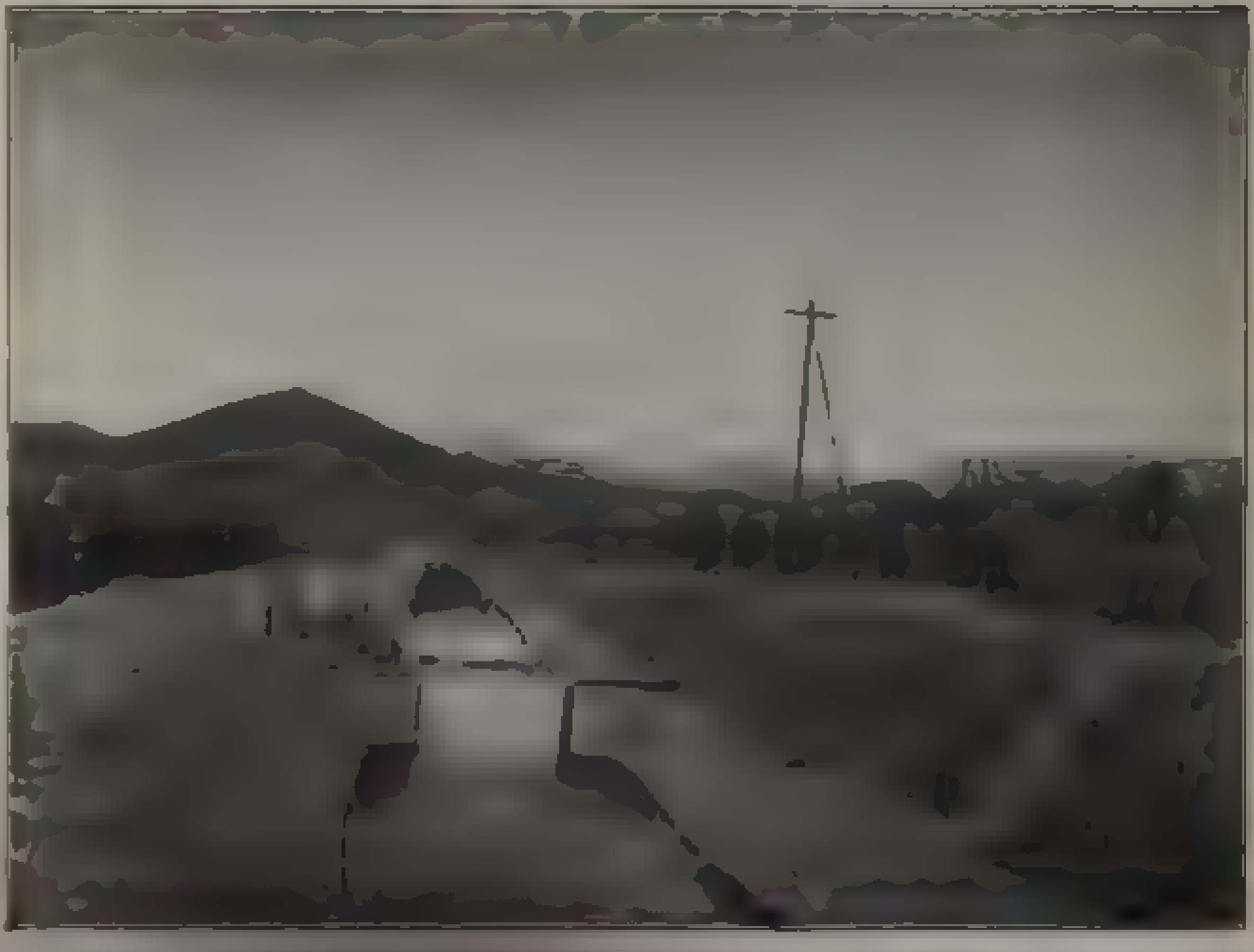
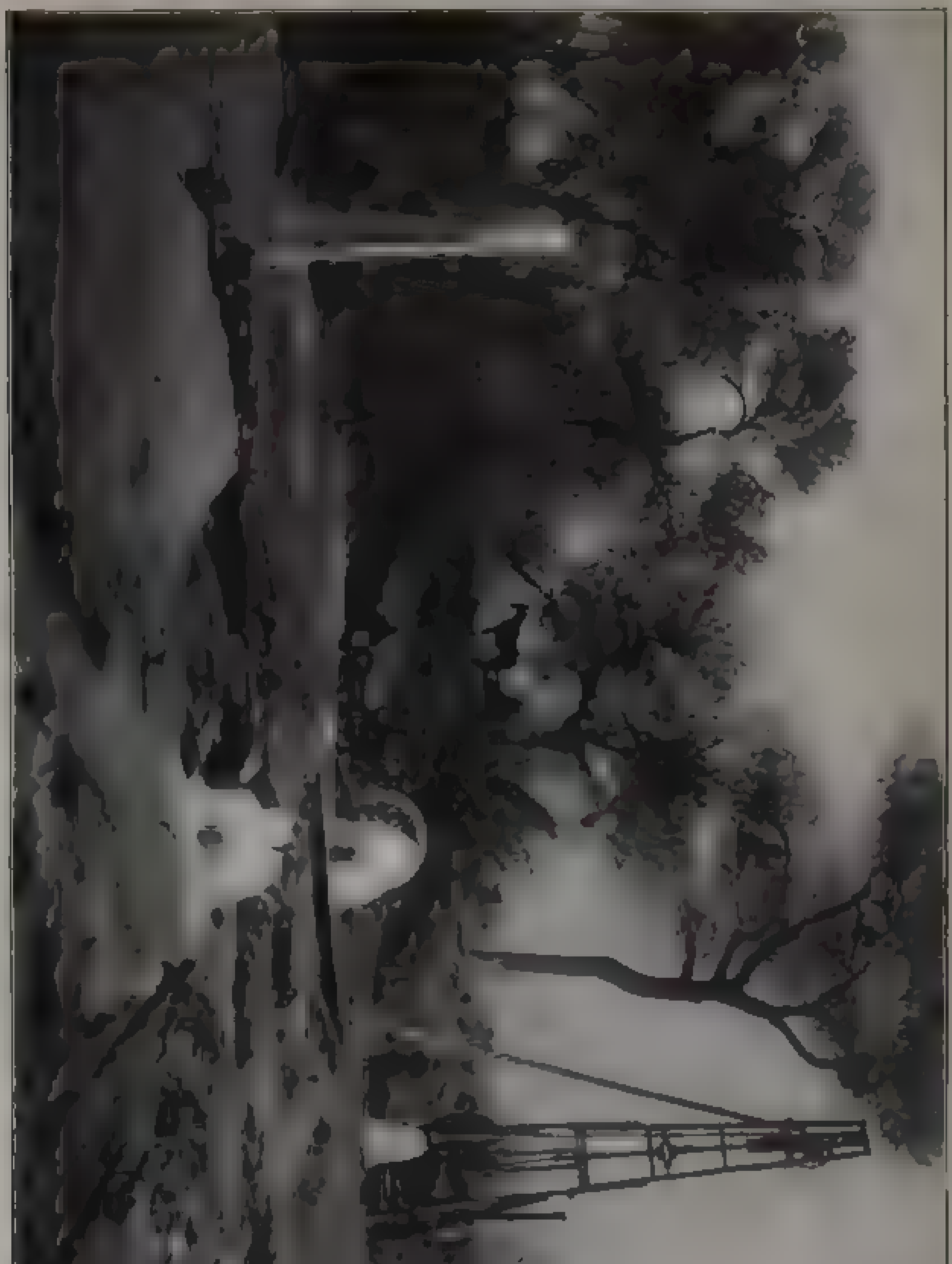


FIG. 2.—DIVISION BULKHEAD OF GAGE CANAL, CALIFORNIA.



ARTESIAN WELLS, HEAD OF GAGE CANAL, CALIFORNIA.

of water from other sources in lieu of its original rights of diversion from the river. The "Wells & Long" right, by appropriation, to divert water from the river, and the "Spring," or "Parish ditch" right to water rising on lands now forming part of the water sources of the Gage Canal are the two remaining claims on which the Gage system bases its right to divert water for irrigation.

The right of an owner to use the water developed by means of artesian wells excavated on his own property has been, so far, undisturbed.

THE GAGE CANAL.

The Gage Canal was constructed in two divisions, the first extending to the Terquisquite arroyo, a distance of 11.9 miles from the headgates, and the second division, built sometime later, extending to the terminal point previously mentioned, a distance of 8.26 miles from said arroyo.

The capacity of the canal for about 6 miles from the head is on the average 4,500 inches; for the remaining part of the first section the average is 3,500 inches, and the second section has an average capacity of 3,000 inches. The cross-sectional dimensions vary only in bottom width—that is, from a width of 10 feet to that of 5 feet; the other dimensions—a depth of 4 feet, with slope of banks 4 feet perpendicular and 3 feet horizontal—remaining the same throughout, while the grade is, in general, for the total length, 2.5 feet per mile.

Up to the present time about 15 miles of canal have been coated with a ¾-inch thickness of cement. Along the line of the canal, where its course crosses the natural depressions, there have been constructed thirteen flumes, the total length being 4,170 feet, the longest being 1,100 feet, with a height of 65 feet; also fourteen tunnels, which, where driven through soft earth, soft sandstone, or cemented sand, were lined on the bottom and on the sides as high as 4.5 feet, with an average thickness of concrete of 6 inches, giving a waterway 6 feet in width, the top being kept in place by a timbered arch. The tunnels in rock are 6.5 feet in width and 6.5 feet in height to center of arch. The aggregate length of these tunnels is 6,178 feet, the longest being 2,320 feet, and the shortest 110 feet. Heavy fills were used, instead of flumes, in four cases, to bridge arroyos, averaging about 6,000 cubic yards of earth each. In every case, in fills, the channel of the canal was lined with cemented masonry to the thickness of 6 inches. Masonry culverts have been constructed through said fills for the purpose of discharging the storm waters drained by these arroyos from the neighboring hills. That these storm waters may be utilized, the discharge through the culverts is regulated by means of gates, retaining just the amount of water that the fills can safely control and permitting the remainder to pass through. This is also accomplished

by the use of an L-shaped culvert, the perpendicular shaft bein built on the upper side of the fill and up to the height necessary t control a certain depth of water, any surplus being discharged into i and then on through the horizontal culvert.

The remaining portions of the canal were constructed through sur faces which offered no special difficulties in carrying on the work.

NATURE OF IRRIGABLE LANDS.

Starting from an average elevation of 1,005 feet above sea level, o line of canal, the slope of the irrigable lands below the flow of th canal is generally on a grade of 100 feet to the mile, and in most case requires little or no grading before planting. Where arroyos inter sect the plains the sides, or bluffs, are generally made capable of culti vation by means of a system of terracing. The land above the cana is not of the same general evenness, but it can be prepared withou much difficulty for planting.

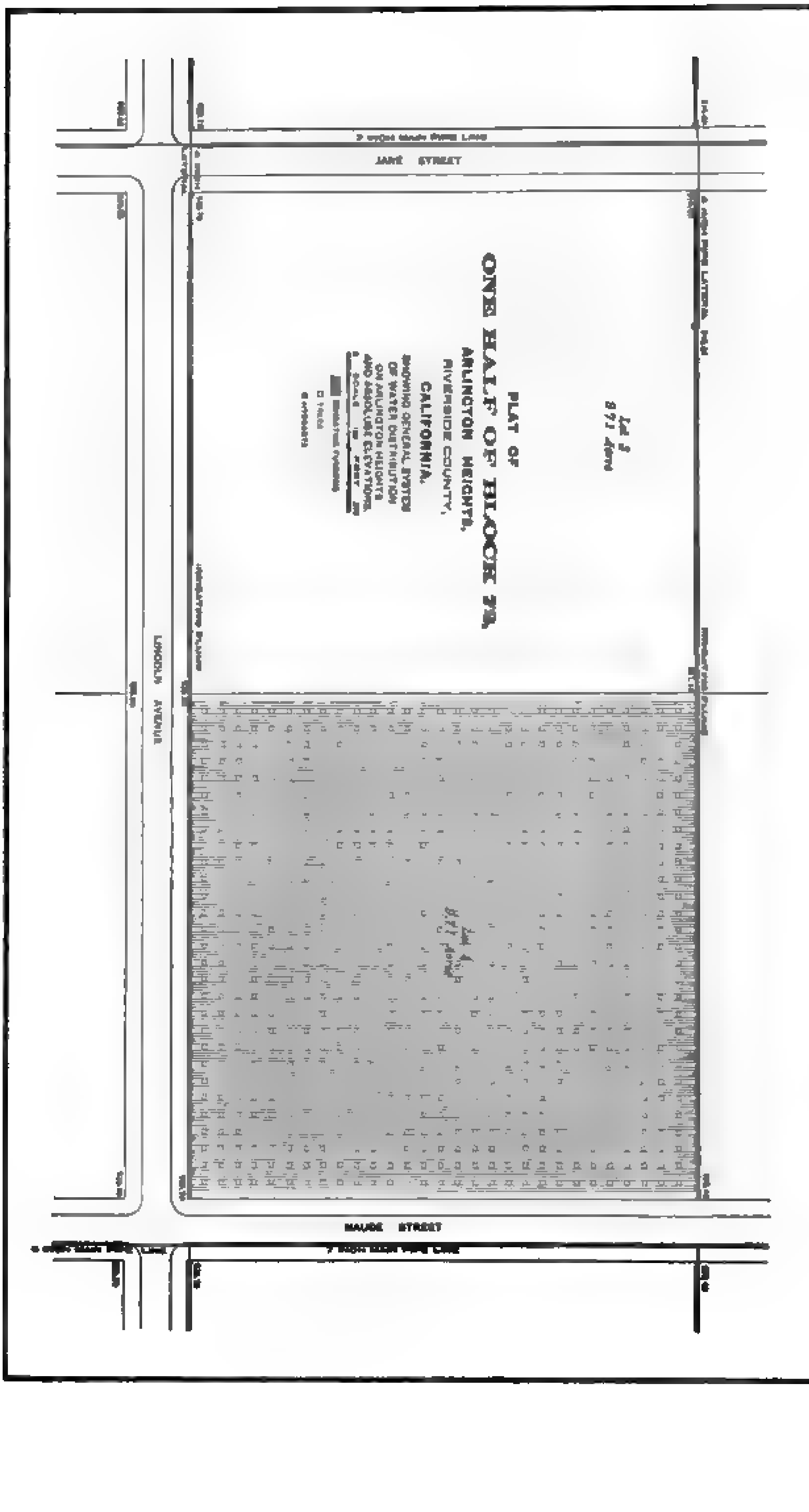
The soil of the above lands is of granite origin, varying from a ligh loam on the higher levels to a medium adobe on the lower, and con cerning all of said soils it has been determined, both by experimen and analysis, that they contain the necessary elements for the produc tion of citrus fruits.

SYSTEM OF DISTRIBUTION.

On the line of canal at points where it is intersected by streets usually at intervals of one-fourth of a mile, masonry bulkheads (Pl XXXVI, fig. 2) are built for the diversion and measurement of th water into the different main pipe lines laid in the streets. The diver sion of the water is effected by means of bulkhead boards insertec across the flow of water in the canal, and kept in place by grooves i the masonry of the bulkhead. The water, being thus obstructed, passes from the canal through a pipe into the bottom of a measuring box, situated in said bulkhead, and then up over a weir, thus registering the total amount of water used for irrigation of the lands depending on that particular pipe for their supply.

At distances of about 650 feet, lateral pipe lines are inserted into the mains (these points being opposite the upper line of each subdivision fronting the street), and from thence are carried to the highest point of each subdivision, except where more than one subdivision can be conveniently irrigated from one hydrant. At the end of each lateral a hydrant and measuring box are attached, and the amount of water used for the irrigation of each parcel of land is measured as it discharges into the flume over a weir built in the measuring box for that purpose.

The system may be better understood from the accompanying map (Pl. XXXVIII) of block 72, Arlington Heights, showing the acreage



PLAT SHOWING SYSTEM OF WATER DISTRIBUTION UNDER GAGE CANAL, CALIFORNIA.

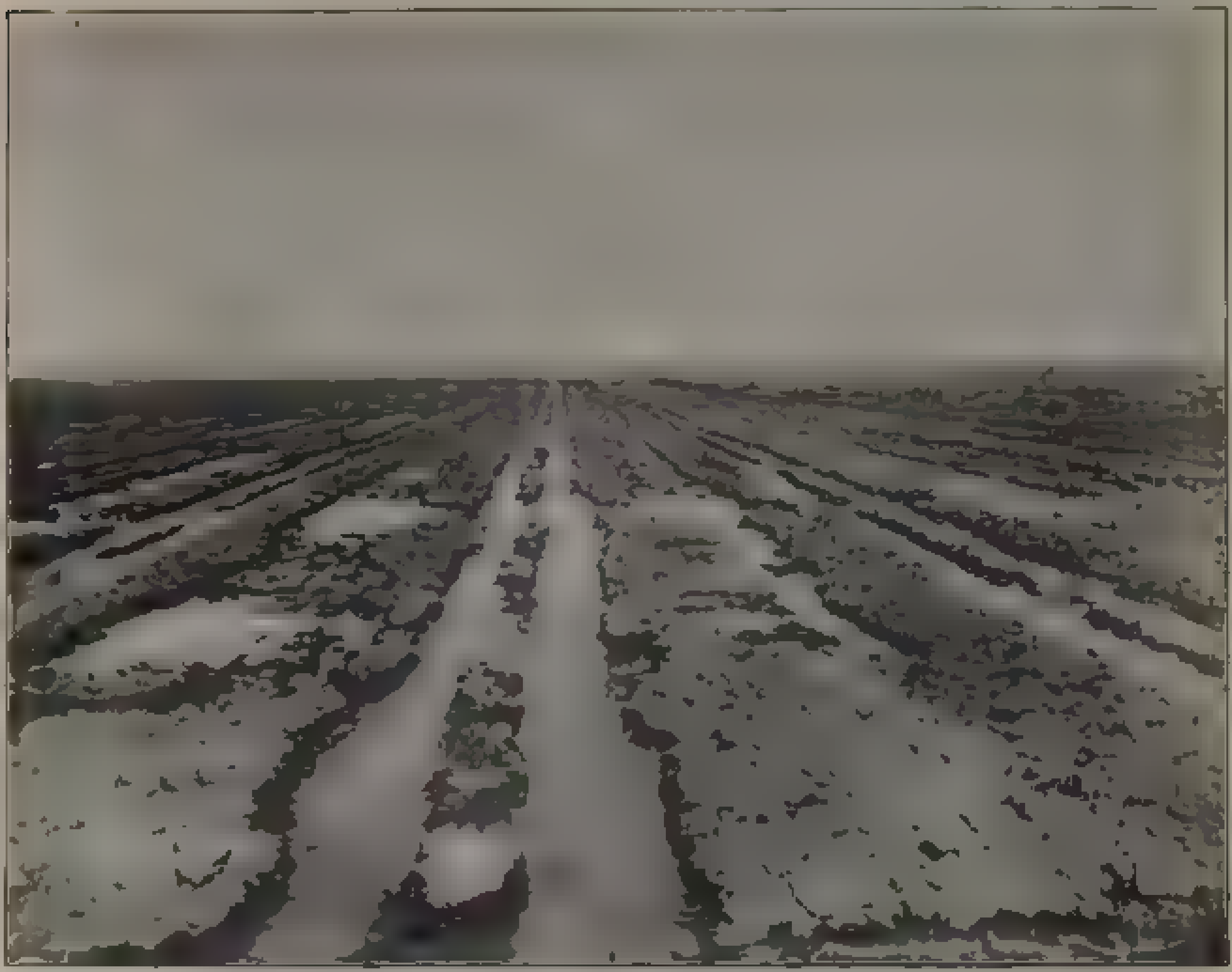


FIG. 1.—A CRUDE METHOD OF FURROW IRRIGATION.

FIG. 2.—AN IMPROVED METHOD OF FURROW IRRIGATION.

and elevation of lots, water distribution, and system of irrigation. The lands of Arlington Heights, generally, are subdivided into about 40-acre blocks by streets and avenues; and said blocks are resubdivided into lots of about 10 acres each. The width of streets and avenues, with one exception, is 80 feet. Victoria avenue, which runs throughout the whole length of the tract, is 120 feet wide, divided into two roadways. All roadbeds are 33 feet wide, and the remainder of width, in each case, is devoted to sidewalks and margins for shade trees. The acreage indicated on maps is strictly exclusive of streets and avenues, hence a purchaser of these lands pays only for the acreage within the boundaries of the lots proper, as indicated on map. On each street there is a main pipe line of riveted sheet steel, leading from the canal, and from which are taken lateral pipes of the same material to the highest point in each lot, or where two lots are in one ownership, as in this case, the distribution of water is made from one point only. These lateral pipes terminate at hydrant boxes situated at the highest point in the upper line of each lot or lots, and in said hydrant box is fixed a "low down" shut-off valve to control the discharge of water. In the side of each hydrant box is fixed a measuring weir 10 inches wide, and of sufficient height to measure at least 40 inches of water passing from hydrant box to "flume." There is placed along the upper line of each lot or lots a line of "distributing flumes" from which, at intervals of about 3.5 feet, the water is discharged into furrows made in the soil for the purpose of irrigation. The trees are planted at intervals of about 21 feet in both directions, and between each row of trees there are five furrows indicated as terminating at "flume," which furrows receive the finely subdivided water discharged from small controllable gates in the flume. As a matter of fact the number of furrows varies from three to six, depending on the age of trees. The elevation above sea level is indicated at the corner of each lot, and from this the direction of the flow of water from hydrants can be inferred. All the lots indicated on accompanying map are now planted, and assumed to be represented on map as indicated on lot 4. (Pl. XXXVIII.)

In the further distribution of the water to the lands there are two systems of irrigation employed. The basin system has been used to some extent in the planting and irrigation of young trees. This is done by forming basins around the roots of the young trees and then filling the basins with water at regular intervals of time during the first year after planting. It has been found that only one-twentieth part of the water is used in this system that is used by the furrow system under the same conditions.

The furrow system (Pl. XXXIX) is the more common method, by means of which all parts of the soil are irrigated, which is absolutely

necessary when the trees reach maturity and are in full bearing. To carry out this latter system a flume leading from the hydrant is carried across the lot just within its upper boundary line and parallel to it, and into the said flume the water from the hydrant is discharged. These flumes are usually made of redwood, but the cement flume is largely superseding the wood. The size varies with the grade and amount of water to be used, and ranges from 8 to 12 inches in width and from 6 to 10 inches in depth. In the side of the flume from which the water is to be discharged 1-inch holes are bored at intervals of from 2 to 3 feet. Furrows are made in the soil by means of a marker or shovel plow, from two to six between the tree rows, and to the lower end of the lot. The amount of water discharged into the furrows is regulated by small gates placed at the outlets in the flume. When the stream of water reaches the lower end it is regulated so as to prevent waste, and is kept thus till the expiration of the time allowed the irrigator.

The opinions of irrigators are various with reference to the duty of water, the variations extending from a duty of 1 inch to 3 acres to a duty of 1 inch to 10 acres. The duty of water for lands under the Gage Canal system is considered to be properly placed at 1 inch to 5 acres, 1 miner's inch being equivalent to one-fiftieth of a cubic foot per second, and equal to a precipitation of rain of nearly 3 inches per month.

The owner of a 10-acre ranch has a water right of 2 inches continuous flow on the basis of the duty of water above mentioned, but as it would be impossible to irrigate with that amount "in continuous flow" his allowance is permitted to accumulate, and at the end of varying periods he receives the equivalent of his water right at such times as he for himself determines, but subject to the by-laws of the Gage Canal Company, which provide "that the users of water must give four days' notice of their desire for a supply of water and to accept the same on any day or days that the company may be able to arrange for the supply thereof."

In the same article it is provided that thirty days is the limit beyond which water can not be accumulated, but this has been amended to read "forty-five days," as some irrigators prefer a longer interval between irrigations—one user applying water to his land three times only during the irrigation season. Whatever interval of time between irrigations may be adopted by the user it is understood that he will have delivered to him his full equivalent amount of water due at the time the service is given him, so that the same amount of water in any case is discharged onto the land during the season.

THE GAGE CANAL COMPANY.

In order that all the users of water under the Gage system of canals might be represented under one organization, so far as their interests in the water for irrigation were concerned, it was determined to incorporate under the State laws the Gage Canal Company.

This company is incorporated for no other purpose than to manage the affairs of its stockholders, and such affairs are confined solely to the maintenance of the general water supply and the distribution and delivery of it onto the lands of the shareholders. It is further provided that neither profit nor loss can arise to the shareholders, as such, from the operations of the company, as all disbursements for the maintenance of the above-described works and services are provided for by an annual assessment on the shareholders in the ratio of shares held by each, and for such sums only as are required to meet their obligations in the above behalf.

The constitution of the company provides for the election of a board of directors by the shareholders, the voting power depending on the number of shares held and each share representing one-tenth of an inch of water.

The board of directors elect a president, secretary-treasurer, and zanjero—the two latter being the executive officers of the company. The zanjero has full and undisputed charge of the water distribution, and no water can be run onto the lands of any stockholder until the discharge hydrant is opened by the zanjero or one of his agents. This system of noninterference by the users of water was adopted from the first, and being universal in its application it has worked with great satisfaction.

The stock of the company consists at present of ten thousand shares, representing 1,000 miner's inches of water. This amount of water was developed and owned by the Riverside Trust Company, Limited, and by it transferred to the canal company, water stock being taken in payment.

The Riverside Trust Company, Limited, to whom Mr. M. Gage transferred all his interests in the above-described estate, was originally, so far as the Gage Canal Company is concerned, the owner of the land and water. In transferring the water to the canal company and taking water stock in lieu thereof, the trust company is required to issue to each purchaser of its lands such number of shares as represents the water to which the lands are entitled on the basis of 1 inch to 5 acres.

The contracts entered into by the purchasers of land under said system provide explicitly that the water once attached to a particular piece of land becomes appurtenant thereto, and can not be transferred to other lands.

In connection with the routine work of the canal company's office

there are certain forms and records which are used to facilitate the work and to keep the record of its working. Among these is a blank form of "water order" which is given to each user of water, and which he fills up and serves upon the zanjero at the company's office. The following is a blank "water order:"

Water order.] Riverside, Cal., ——, 189—.

THE GAGE CANAL COMPANY.

Please deliver —— inches of water for use on lots —— block —— commencing on the morning of —— the —— day of ——, 189— for —— days.

Signature —— ——.

The company will not undertake to deliver water unless this form, properly filled up and signed, is left at its Camp Arlington office, at least four (4) days before the water is required. Water will be delivered to shareholders in accordance with Section II of Article IX of the company's by-laws, each order having precedence according to the date of its delivery at the company's office as above.

N. B.—Anyone found tampering with the hydrants, measuring boxes, or any of the company's property will be prosecuted under sections 499, 592, 625, of the penal code.

In the same office is kept a "water book" in which is entered daily the total flow of water and the particular lands to which it is distributed. From such a record a complete history of the water service from day to day and from year to year can be determined.

SPECIAL INVESTIGATIONS IN 1899.

For the purpose of more accurately determining the amount of water used in the irrigation of lands under the Gage Canal system during the year 1899, the total area was divided into three districts. (See Map, Pl. XXXV, p. 132). These districts lie one below the other along the course of the canal. Measuring weirs have been placed at the upper boundaries of the districts, to determine the flow of the canal at those points. All the water passes weir No. 1. What water is not used in district No. 1 passes weir No. 2, and that left after district No. 2 has been supplied flows through weir No. 3 to district No. 3.

These lands require a practically constant supply of moisture throughout the year, except that in winter evaporation from the ground and trees is less. When this moisture is not supplied by rainfall it must be supplied by irrigation, so that the canal is in operation throughout the entire year. The crop year for citrus fruits does not coincide with the calendar year, but may be considered to extend from October to October, for which period the measurements are given.

All measurements made under the Gage Canal are in miner's inches, 50 inches being considered equal to 1 cubic foot per second. The daily records are given in miner's inches continuous flow for twenty-four hours, as this unit is used almost exclusively in California.

The rainfall for the period from October 1, 1898, to September 30, 1899, was as follows:

Rainfall as measured at Camp Arlington, from October 1, 1898, to September 30, 1899.[1]

Month.	Rainfall.	Month.	Rainfall.
1898.	*Inches.*	1899.	*Inches.*
November 20	0.01	March 9	0.03
		March 16	.19
December 9	.96	March 17	.31
December 15	.42	March 20	.31
		March 21	.03
	1.38	March 28	.03
1899.			.90
January 2	.38		
January 3	.07	May 6	.03
January 8	.14	May 7	.10
January 10	1.02		
January 11	.33		.13
January 12	.15		
		June 1	.24
	2.09	June 2	.04
		June 3	.02
February 1	.16		
February 2	.60		.30
February 5	.02		
February 24	.11	Total rainfall	5.70
	.89		

[1] There was no rainfall from June 4 to October 6, 1899.

DISTRICT NO. 1.

District No. 1 includes the lands known as the East Riverside Devel opment, and extends from the north boundary of T. 2 S., R. 4 W., San Bernardino meridian, at a distance of 5.68 miles from the head gates to the Terquisquite arroyo, or No. 9 flume, a distance of 11.90 miles from the headgates, and contains 3,595 acres now under irriga tion, all planted to citrus fruits. The planting in this district commenced in the year 1887, and from year to year additional planting has been done up to the year 1896. The following tables show the water used in this district from October 1, 1898, to September 30, 1899:

Water used daily on lands in district No. 1 under Gage Canal, October 1, 1898, to September 30, 1899.

[See diagram, Pl. VII, p. 74. Measurements in miner's inches.]

Day.	October, 1898.	November, 1898.	December, 1898.	January, 1899.	February, 1899.	March, 1899.	April, 1899.	May, 1899.	June, 1899.	July, 1899.	August, 1899.	September, 1899.
1	671	408	406	636	96	750	224	700	652	730	696	687
2	655	477	406	[1] 212	([1])	791	431	660	626	701	728	747
3	660	583	368	304	66	699	443	787	628	716	724	745
4	636	550	172	217	124	717	591	698	692	748	716	720
5	645	574	209	293	164	672	704	748	700	728	701	703
6	655	550	212	319	234	688	776	734	676	726	705	710
7	655	513	199	404	363	722	682	771	706	754	710	716
8	650	357	286	337	315	698	768	722	727	770	739	714
9	566	486	180	342	320	701	786	728	747	780	709	712
10	609	576	218	270	212	682	782	711	775	714	694	690

Water used daily on lands in district No. 1 under Gage Canal, October 1, 1898, to September 30, 1899—Continued.

[See diagram, Pl. VII, p. 74. Measurements in miner's inches.]

Day.	October, 1898.	November, 1898.	December, 1898.	January, 1899.	February, 1899.	March, 1899.	April, 1899.	May, 1899.	June, 1899.	July, 1899.	August, 1899.	September, 1899.
11	593	676	300	(1)	290	693	790	697	722	734	682	695
12	592	634	521	66	585	713	679	749	731	737	644	687
13	604	564	497	290	417	778	701	658	717	717	[illegible]	704
14	565	591	498	56	324	768	692	717	721	738	677	698
15	550	594	(1)	102	513	759	745	727	737	730	744	719
16	511	566	246	81	697	678	741	698	747	691	751	712
17	579	649	59	737	746	713	815	742	756	731	742	709
18	602	644	70	44	742	675	791	716	758	739	749	694
19	561	613	230	69	646	576	775	704	744	736	775	705
20	541	451	293	32	691	458	778	648	759	718	742	698
21	508	542	268	36	799	666	752	670	759	691	724	702
22	522	559	218	204	798	567	753	692	746	750	706	691
23	435	580	306	150	846	494	746	758	765	697	685	692
24	441	503	396	131	791	399	752	718	766	774	708	674
25	491	414	359	83	771	80	817	693	752	759	657	664
26	524	358	260	190	690	(2)	736	725	750	727	670	718
27	494	432	390	173	713	......	773	747	750	716	654	732
28	634	442	110	154	798	......	788	754	686	704	695	668
29	644	553	541	139	......	......	733	755	760	690	656	648
30	422	436	500	190	......	......	690	697	779	715	656	642
31	461	......	575	275	......	316	......	692	......	698	640	......
Total	17,716	15,825	9,662	6,507	13,541	16,433	21,176	22,146	21,802	22,514	21,737	20,939
Acre-feet	702.78	627.77	383.29	258.13	537.16	651.89	840.04	878.52	864.87	893.12	862.29	830.60

[1] Rain. [2] Water out for repairs.

Duty of water in district No. 1 under Gage Canal, 1898 and 1899.

Month.	Area.	Water used.		Depth.	Area per miner's inch.[1]
	Acres.	*Miner's inches.*	*Acre-feet.*	*Feet.*	*Acres.*
1898.					
October	3,595	17,716	702.78	0.1955	....
November	3,595	15,825	627.77	.1746	....
December	3,595	9,662	383.29	.1066	....
1899.					
January	3,595	6,507	258.13	.0718	....
February	3,595	13,541	537.16	.1494	....
March	3,595	16,433	651.89	.1813	....
April	3,595	21,176	840.04	.2337	....
May	3,595	22,146	878.52	.2444	....
June	3,595	21,802	864.87	.2405	....
July	3,595	22,514	893.12	.2491	....
August	3,595	21,737	862.29	.2399	....
September	3,595	20,939	830.60	.2310	....
Total irrigation	3,595	209,997	8,330.46	2.3178	6.25
Rainfall	......	......	....	.475	....
Total water received during year				2.7928	....

[1] Continuous flow for the year.

DISTRICT NO. 2.

District No. 2 includes all the lands of Arlington Heights and some adjacent territory, extending from the Terquisquite arroyo to the end of the canal, a distance of 20.16 miles from the headgates, and contains 2,871 acres now under irrigation.

Some of the land in this district lies above the flow of the canal. About 150 acres of these lands have been planted to citrus fruit trees, and as the higher planted boundary of said lands is at an elevation of 100 feet above the canal, and the supply of water needed for their cultivation is taken from the canal, a pumping company has been organized for the purpose of distributing the water to these higher levels. The users of water on these lands are related, in the first instance, to the Gage Canal in every respect as those using water on lands below the canal, but in addition they have to pay the cost of pumping in the ratio of the shares they hold in the Gage Canal Company.

In order to form correct estimates of results it will be necessary to give details of the time of planting of the portions of district No. 2 which are under our immediate care, and the particulars of which we have in our own keeping. These particulars, however, with reference to a part will serve fairly well to form estimates of the whole.

It will be kept in view that the orange or lemon tree can hardly be said to yield fruit until after the third year from time of planting in orchard form, and that the yearly increase in product continues at least to the fifteenth year.

The following are the times of planting of said portions of district No. 2:

Date of planting trees in district No. 2.

	Acres.		Acres.
1891	690.10	1896	14.31
1892	130.04	1897	58.86
1893	667.57	1898	16.66
1894	79.80		
1895	10.00	Total	1,666.84

The total product from the 1,666.84 acres above tabulated can not be given for this present year, but is estimated as follows:

	Packed boxes.
Oranges, all varieties	174,813
Lemons, all varieties	46,173
Total	220,986

The remaining acreage in district No. 2, amounting to 1,205 acres, excepting 120 acres planted between 1896 and the present year, were planted in the year 1891, and will exceed in average product the acre-

age above shown. The water used upon the above acreage is shown in the following table:

Water used daily on lands in district No. 2 under Gage Canal, October 1, 189[illegible] September 30, 1899.

[See diagram, Pl. VIII, p. 74. Measurements in miner's inches.]

Day	October, 1898.	November, 1898.	December, 1898.	January, 1899.	February, 1899.	March, 1899.	April, 1899.	May, 1899.	June, 1899.	July, 1899.	August, 1899.	September, 1899.
1	499	730	522	350	350	412	383	556	592	438	482	[illegible]
2	510	685	510	172	(¹)	400	300	586	601	459	451	[illegible]
3	520	553	517	(¹)	75	537	485	501	569	508	454	[illegible]
4	520	597	540	375	125	535	520	533	543	482	457	[illegible]
5	516	573	455	375	150	595	514	490	538	463	442	[illegible]
6	506	555	560	390	200	566	615	513	549	436	436	[illegible]
7	501	630	560	390	200	610	551	517	520	399	45[illegible]	[illegible]
8	493	600	610	495	175	590	485	562	496	382	410	[illegible]
9	560	560	200	490	175	532	507	507	473	440	443	[illegible]
10	544	610	(¹)	(²)	200	602	530	583	445	433	46[illegible]	[illegible]
11	557	606	220	(¹)	200	616	541	569	514	430	47[illegible]	[illegible]
12	574	549	300	(¹)	170	615	569	582	497	446	511	[illegible]
13	577	573	350	(¹)	200	470	596	612	487	470	49[illegible]	[illegible]
14	591	595	400	100	225	455	570	559	482	445	490	[illegible]
15	605	587	(¹)	100	225	515	562	531	455	434	434	[illegible]
16	660	576	(¹)	65	240	540	585	548	440	451	449	[illegible]
17	579	617	265	115	230	490	502	515	433	461	457	[illegible]
18	523	540	290	165	260	515	545	544	434	465	463	[illegible]
19	586	596	220	140	275	595	537	539	434	449	473	[illegible]
20	615	602	355	140	275	675	509	592	441	480	490	[illegible]
21	581	608	390	190	280	500	490	569	437	480	525	[illegible]
22	610	610	425	190	350	425	475	596	427	423	495	[illegible]
23	716	582	400	165	350	517	506	584	434	469	511	[illegible]
24	725	610	475	195	376	487	492	529	405	403	498	[illegible]
25	635	560	325	225	377	519	450	489	422	428	498	[illegible]
26	622	515	390	250	412	(²)	510	489	392	458	497	[illegible]
27	667	475	440	248	420	......	480	452	421	457	511	[illegible]
28	615	531	505	250	345	......	452	468	474	452	481	[illegible]
29	512	475	530	245	......	......	563	487	402	464	503	[illegible]
30	671	520	525	275	......	......	543	526	400	436	513	[illegible]
31	690		575	325	......	250	......	526	......	453	525	
Total	18,000	17,118	11,704	6,460	6,830	13,081	15,239	16,569	14,167	13,924	14,687	[illegible]
Acre-feet	714.05	679.06	464.29	256.26	270.94	518.92	604.52	656.65	561.60	552.36	582.62	[illegible]

¹ Rain. ² Water out for repairs.

DISTRICT NO. 3.

District No. 3 includes lands lying beyond the terminus of the Gage Canal. This territory is known as the San Jacinto estate. The water for said lands is taken from the Gage Canal and distributed by means of small cemented ditches and pipe lines at the expense of the San Jacinto Company. The total acreage now under irrigation in district No. 3 is 530 acres. The first planting was done in the year 1895, and the company has added to the planted area each year since. The water used in this district is shown by the following table:

Water used daily on lands in district No. 3 under Gage Canal, October 1, 1898, to September 30, 1899.

[See diagram, Pl. IX, p. 74. Measurements in miner's inches.]

Day.	October, 1898.	November, 1898.	December, 1898.	January, 1899.	February, 1899.	March, 1899.	April, 1899.	May, 1899.	June, 1899.	July, 1899.	August, 1899.	September, 1899.
1	80	95	90	25	......	88	......	82	108	83	74	66
2	80	65	90	20	......	50	......	92	110	91	62	65
3	80	50	90	......	......	88	90	99	111	7	73	80
4	80	75	90	......	......	90	80	92	107	20	82	98
5	80	75	90	......	......	80	80	85	109	49	93	92
6	75	70	90	......	......	70	85	81	108	89	86	80
7	80	70	90	40	......	80	85	83	107	93	78	82
8	88	70	90	40	......	85	85	78	105	94	78	77
9	95	55	([1])	40	......	75	85	93	103	85	77	85
10	88	65	([1])	......	......	85	85	94	108	99	85	85
11	86	70	80	......	......	85	75	81	106	77	76	76
12	80	68	......	......	......	85	80	80	110	73	76	77
13	85	65	......	......	......	70	75	78	109	77	75	84
14	85	65	......	......	......	75	80	71	110	81	87	89
15	95	65	......	......	......	75	65	79	106	79	87	81
16	80	80	......	35	......	90	70	82	101	79	75	90
17	93	85	20	35	......	85	50	85	94	64	93	78
18	97	85	20	35	......	85	40	68	96	47	86	92
19	70	80	20	35	......	90	45	85	96	64	85	87
20	80	90	20	35	......	......	55	98	94	53	65	65
21	80	90	20	35	......	......	57	103	88	75	80	63
22	95	90	25	35	......	......	70	65	86	82	87	100
23	95	90	25	35	50	......	82	......	94	89	99	89
24	85	90	25	25	84	......	74	51	93	82	92	92
25	80	90	25	25	88	......	75	88	95	68	89	95
26	95	85	20	25	88	......	96	108	95	66	98	88
27	90	85	25	27	80	......	100	109	70	73	94	76
28	82	90	25	25	80	......	98	85	91	85	94	84
29	85	90	20	25	......	......	85	90	93	82	90	92
30	95	80	25	......	......	......	95	104	81	71	89	91
31	100	......	25	......	......	......	......	104	......	85	81	......
Total	2,659	2,323	1,140	597	470	1,531	2,142	2,593	2,984	2,262	2,586	2,499
Acre-feet	105.48	92.15	45.22	23.68	18.64	60.73	84.97	102.86	118.37	89.73	102.59	99.13

[1] Rain.

Duty of water in district No. 3 under Gage Canal, 1898 and 1899.

Month.	Area.	Water used.		Depth.	Area per miner's inch.[1]
1898.	*Acres.*	*Miner's inches.*	*Acre-feet.*	*Feet.*	*Acres.*
October	580	2,650	105.45	0.1980	....
November	580	2,235	92.15	.1738	....
December	580	1,140	45.22	.0856	....
1899.					
January	580	587	25.09	.0447	....
February	580	[illegible]	18.64	.0352	....
March	580	1,[illegible]	60.72	.1146	....
April	580	2,143	84.97	.1608	....
May	580	2,[illegible]	102.86	.1941	....
June	580	2,[illegible]	118.27	.2223	....
July	580	2,[illegible]	80.73	.1658	....
August	580	2,[illegible]	102.59	.1986	....
September	580	2,[illegible]	90.13	.1870	....
Total irrigation	580	23,785	943.65	1.7802	8.1[illegible]
Rainfall	......	....	....	.475	....
Total water received during year	......	....	....	2.2552	....

[1] Continuous flow for the year.

The following table gives the duty of water under the Gage Canal as a whole. No allowances are made in any of the tables for losses from seepage and evaporation. Seepage is practically eliminated, as most of the canal is cemented, and measurements of evaporation show a loss of only about 1 per cent, so that losses from these sources need not be considered. The duty for the whole canal is as follows:

Duty of water under Gage Canal, 1898 and 1899.

Month.	Area.	Water used.		Depth.	Area per miner's inch.[1]
1898.	*Acres.*	*Miner's inches.*	*Acre-feet.*	*Feet.*	*Acres.*
October	6,996	38,375	1,522.31	0.2176	....
November	6,996	35,265	1,399.94	.2000	....
December	6,996	22,505	892.80	.1276	....
1899.					
January	6,996	13,564	538.08	.0769	....
February	6,996	20,841	826.75	.1182	....
March	6,996	31,045	1,231.54	.1760	....
April	6,996	38,557	1,529.58	.2186	....
May	6,996	41,292	1,638.03	.2341	....
June	6,996	38,943	1,544.85	.2208	....
July	6,996	38,700	1,535.21	.2194	....
August	6,996	39,010	1,547.50	.2212	....
September	6,996	37,211	1,476.25	.2110	....
Total irrigation	6,996	395,313	15,681.84	2.2414	6.46
Rainfall	......	....	....	.475	....
Total water received	......	....	....	2.7164	....

[1] Continuous flow for the year.

The preceding tables show the averages for the several districts and for the canal as a whole. There are wide differences in the practices of individuals, which are brought out in the tables which follow. These tables, in addition to showing the quantities of water used,

illustrate the system used in delivering water (see page 134), and show the periods between irrigations and the quantities used at each irrigation.

Water used by N. P. Cayley on lots 3 and 4, block 72, October 1, 1898, to September 30, 1899.

[See map, Pl. XXXVIII, p. 134.]

Ordered.					Received.		
Date.	Amount.	Time for which ordered. Date.	Time for which ordered. No. of days.	Place.	Date.	Amount.	Remarks.
	Miner's inches.					*Miner's inches.*	
Oct. 12, 1898	30	Oct. 15–17	2	Lot 3	Oct. 16–19	120	30 inches for 4 days.
Oct. 12, 1898	20	Oct. 17–20	3	Lot 4			
Nov. 11, 1898	30	Nov. 12–16	4	Lots 3 and 4	Nov. 12	35	
					Nov. 13–15	90	30 inches for 3 days.
Feb. 3, 1899	30	Feb. 8–12	4	Lots 3 and 4	Feb. 8, 9	60	30 inches for 2 days.
					Feb. 10	25	
					Feb. 11	30	
Mar. 4, 1899	20	Mar. 4–7	3	Lot 3	Mar. 9–12	80	20 inches for 4 days.
Mar. 10, 1899	20	Mar. 11–14	3	Lot 4	Mar. 19–21	60	20 inches for 3 days.
Apr. 16, 1899	30	Apr. 21–25	4	Lots 3 and 4	Apr. 23–26	120	30 inches for 4 days.
May 8, 1899	30	May 23–27	4	Lots 3 and 4	May 22–25	120	Do.
June 19, 1899	30	June 23–27	4		July 2–6	150	30 inches for 5 days.
Aug. 26, 1899	30	Sept. 1–5	4		Sept. 8–10	84	28 inches for 3 days.
					Sept. 11	25	
Total						999	

Summary.

Area irrigated ... acres	20.00
Water used ... acre-feet	39.63
Depth of irrigation ... feet	1.98
Depth of rainfall ... do	.47
Total depth of water received by land ... do	2.45

Water used by J. D. Carscaden on lot 2, block 39, October 1, 1898, to September 30, 1899.

Ordered.				Received.		
Date.	Amount.	Time for which ordered. Date.	Time for which ordered. No. of days.	Date.	Amount.	Remarks.
	Miner's inches.				*Miner's inches.*	
Nov. 17, 1898	20	Nov. 22–25	3	Nov. 22–24	60	20 inches for 3 days.
Apr. 27, 1899	20	May 3–6	3	May 3–5	60	Do.
				May 6	15	
July 10, 1899	20	July 17–20	3	July 17	17	
				July 18, 19	40	20 inches for 2 days.
				July 20	25	
				July 21	10	
Sept. 11, 1899	20	Sept. 18–21	3	Sept. 18	25	
				Sept. 19	30	
				Sept. 20	20	
Total					302	

Summary.

Area irrigated	acres..	10.00
Water used	acre-feet..	11.98
Depth of irrigation	feet..	1.20
Depth of rainfall	do...	.47
Total depth of water received by land	do...	1.67

Water used by Gulick Brothers on block 64, October 1, 1898, to September 30, 1899.

Ordered. Date.	Ordered. Amount.	Time for which ordered. Date.	Time for which ordered. No. of days.	Received. Date.	Received. Amount.	Remarks.
	Miner's inches.				*Miner's inches.*	
				Oct. 1	20	
				Oct. 2	25	
				Oct. 3-6	120	30 inches for 4 days.
				Oct. 7	40	
Sept. 29, 1898	30	Oct. 3-13	10	Oct. 8	45	
				Oct. 9-11	90	30 inches for 3 days.
				Oct. 12, 13	30	15 inches for 2 days.
				Oct. 14, 15	40	20 inches for 2 days.
				Oct. 16	15	
				Nov. 1	22	
				Nov. 2, 3	50	25 inches for 2 days.
Oct. 31, 1898	30	Nov. 3-13	10	Nov. 4-10	210	30 inches for 7 days.
				Nov. 11	15	
				Nov. 12	20	
				Nov. 13	10	
				Dec. 27-31	150	30 inches for 5 days.
Dec. 10, 1898	30	Dec. 14-24	10	Jan. 1-5, 1899	120	30 inches for 4 days.
				Jan. 6-8	60	20 inches for 3 days.
				Jan. 9	15	
Feb. 22, 1899	30	Feb. 25-Mar. 7	10	Feb. 25-Mar. 7	330	30 inches for 11 days.
				Mar. 8, 9	20	10 inches for 2 days.
Apr. 8, 1899	30	Apr. 13-23	10	Apr. 13-23	330	30 inches for 11 days.
				Apr. 24-26	45	15 inches for 3 days.
				May 17-23	210	30 inches for 7 days.
May 12, 1899	30	May 17-27	10	May 26-31	150	30 inches for 5 days.
				June 3, 4	20	10 inches for 2 days.
				June 19, 20	60	30 inches for 2 days.
				June 21, 22	50	25 inches for 2 days.
				June 23	27	
June 12, 1899	30	June 19-29	10	June 27	30	
				June 28, 29	50	Do.
				June 30	22	
				July 1	22	
				July 6, 7	20	10 inches for 2 days.
				July 25-31	210	30 inches for 7 days.
July 10, 1899	30	July 17-27	10	Aug. 3, 4	60	30 inches for 2 days.
				Aug. 5, 6	20	10 inches for 2 days.
				Aug. 28-31	120	30 inches for 4 days.
Aug. 18, 1899	30	Aug. 24-Sept. 3		Sept. 1-6	180	30 inches for 6 days.
				Sept. 10	10	
Total					3,083	

Summary.

Area irrigated	acres..	51.30
Water used	acre-feet..	122.30
Depth of irrigation	feet..	2.38
Depth of rainfall	do...	.47
Total depth of water received by land	do...	2.85

Water used by C. C. Quinn on lot 4, block 73, October 1, 1898, to September 30, 1899.

Ordered.				Received.		
Date.	Amount.	Time for which ordered. Date.	No. of days.	Date.	Amount.	Remarks.
	Miner's inches.				*Miner's inches.*	
No order				Oct. 13–15	60	20 inches for 3 days.
Nov. 2, 1898	20	Nov. 14–17	3	Nov. 14–16	60	Do.
Dec. 10, 1898	20	Dec. 14–17	3			Rain on the 14th.
Feb. 16, 1899	20	Feb. 22–25	3	Mar. 6, 7	20	10 inches for 2 days.
Apr. 9, 1899	20	Apr. 12–15	3	Apr. 13–15	60	20 inches for 3 days.
May 7, 1899	20	May 13–16	3	May 13–15	60	Do.
June 7, 1899	20	June 13–16	3	June 17–19	60	Do.
July 12, 1899	20	July 17–20	3	July 22–24	60	Do.
No order				Aug. 27–29	60	Do.
Sept. 18, 1899	20	Sept. 27–30	3	Sept. 30–Oct. 2	60	Do.
Total					500	

Summary.

Area irrigated	acres	10.00
Water used	acre-feet	19.83
Depth of irrigation	feet	1.98
Depth of rainfall	do	.47
Total depth of water received by land	do	2.45

Water used by C. E. Kennedy on block 82, October 1, 1898, to September 30, 1899.

Ordered.				Received.		
Date.	Amount.	Time for which ordered. Date.	No. of days.	Date.	Amount.	Remarks.
	Miner's inches.				*Miner's inches.*	
Oct. 4, 1898	35	Oct. 10–13	3	Oct. 7–10	120	30 inches for 4 days.
Nov. 11, 1898	21	Nov. 14–19	5	Nov. 15–20	120	20 inches for 6 days.
Jan. 6, 1899	21	Jan. 9–14	5	Jan. 7–9	60	20 inches for 3 days. Rain.
Feb. 14, 1899	35	Feb. 17–20	3	Feb. 17–21	200	40 inches for 5 days.
Apr. 13, 1899	35	Apr. 17–20	3	Apr. 26–28	105	35 inches for 3 days.
May 25, 1899	35	May 31–June 3	3	June 3–5	105	Do.
June 27, 1899	35	July 7–10	3	July 9–10.	70	35 inches for 2 days.
				July 11	25	
No order				Aug. 20–23	140	35 inches for 4 days.
				Aug. 24	15	
Sept. 25, 1899	35	Sept. 26–29	3	Sept. 26–28	105	35 inches for 3 days.
Total					1,065	

Summary.

Area irrigated	acres	17.00
Water used	acre-feet	42.28
Depth of irrigation	feet	2.48
Depth of rainfall	do	.47
Total depth of water received by land	do	2.95

delivery can be carried out on a canal
of streams or wells, and without storag

As was said, the duty assumed in th
Company is 1 inch to 5 acres. This wo
to a depth of 0.24 foot per month, or
water was used constantly, but there is
in the use during the rainy season. T
show an average depth of 2.24 feet for
has the water used come up to the assu
of the shortage occurred in the mon
drought of the past three years has re
it is possible that irrigators have not
would have, had a larger supply been a

NEBRASKA.

DUTY OF WATER IN NEBRASKA.

By Special Agent O. V. P. Stout,
Professor of Civil Engineering, University of Nebraska.

GAGINGS OF THE NORTH PLATTE RIVER.

Gaging stations have been maintained for several years by the United States Geological Survey at Gering and at Camp Clarke on the North Platte River in Nebraska. From the records of these stations the daily mean discharge of the river at those points during the open season of each year has been estimated. In the spring of 1899 it seemed that a comparatively small amount of work in addition to that of the Geological Survey would secure results which would be of value as bearing upon the practice of irrigation under the canals which divert water from the river at points between the two gaging stations. The plan was to obtain the area of land irrigated by water diverted between these two stations and to obtain from the discharge records of the river the approximate quantity of water used on this land. The work would be simplified by the total absence of surface tributaries entering on this length of the river.

Soon after the work was commenced it was arranged that the expense should be borne by the Agricultural Experiment Station of the University of Nebraska. In view of the limited sum available, it was decided that an effort should be made to secure only general results covering the considerable territory involved. It is a matter of regret that the results, in addition to being general in their nature, are uncertain in value to an extent greater than was anticipated when the work was undertaken.

With a view to securing increased precision in the records of the discharge of the river, it was determined that the number of measurements of discharge should be increased by about 25 per cent. This has been done, and, although certain peculiarities to which attention will be invited appear in the report, there is no reason to suspect that the results have been less accurate than the best which can be obtained in streams v the shifting, changeable character of the North J

The following table gives the discharge of the river at [illegible] gaging stations:

Discharge of North Platte River at gaging stations in Nebraska in 1899.

Date	Mean discharge—Gering.	Mean discharge—Camp Clarke.	Gering in excess of Camp Clarke.
	Cubic feet per second.	*Cubic feet per second.*	*Acre-feet.*
April 11-20	9,228	7,735	[illegible]
April 21-30	9,689	7,782	[illegible]
May 1-10	8,020	6,505	[illegible]
May 11-20	9,412	8,902	10,110
May 21-31	11,344	11,900	....
June 1-10	12,065	14,119	....
June 11-20	15,706	14,423	25,440
June 21-30	20,304	20,911	...
July 1-10	16,543	19,236	
July 11-20	11,081	11,839	......
July 21-31	6,287	6,110	3,890
August 1-10	4,199	3,974	4,470
August 11-20	2,895	2,977	......
August 21-31	1,904	1,668	5,140
September 1-10	995	909	1,706
September 11-20	718	995	......
September 21-30	808	1,323	......
October 1-10	895	1,264	......
October 11-20	1,366	1,471	......

Crops irrigated in 1899 by diversion between Gering, Nebr., and Camp Clarke, Nebr.

Name of canal.	Corn.	Alfalfa.	Oats.	Wheat.	Hay.	Garden.	Barley.	Trees.	Millet.	Total.
	Acres.	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*	*Acres.*
Minatare	[illegible]	339	287	294	3,297	48	20	35	......	[illegible]
Steamboat	[illegible]	260	15	10	......	......	......	......	......	[illegible]
Castle Rock	507	964	264	401	1,280	86	15	20	......	[illegible]
Nine Mile, or Bayard	251	302.5	116	253	2,216	32	9	......	9	[illegible]
Short Line	67	20	54	77	450	10	......	......	......	[illegible]
Chimney Rock	122	200	66	44	715	11	8	......	10	[illegible]
Alliance	107	210	53	49	141	7.5	......	......	0.5	[illegible]
[illegible]	[illegible]	25	10	13	......	......	......	......	......	[illegible]
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	144.5	[illegible]	[illegible]	19.5	[illegible]

Examination and analysis of the discharge record at the two river stations for the balance of the season only confirm the conclusion which the facts already pointed out would justify, namely, that even general approximate conclusions respecting the quantity of water used for irrigation from a stream of the size and character of the one under discussion can be based only on direct observation of the amount of water carried in the canals.

GAGINGS OF CANALS.

Aside from the extra gagings of the river, it was proposed to secure as full data as practicable in regard to operations under the irrigation canals. To secure an estimate of the amount of water diverted into each of the several canals the following plan was relied upon:

The hydrographer was instructed to the effect that opportunity to gage canals was to be sought as he traveled up and down the river between Gering and Camp Clarke. Gage rods were set in the canals at some point above the first diversion of water, the ditch riders agreeing to make and report daily observations of the height of canal water on the rods. The adoption of this method, at best lacking in precision, presupposes a considerable number of gagings distributed throughout the season and that the records of voluntary observers will be fairly complete. Reasonable certainty attaches to the results which are submitted about in proportion as these suppositions have been found correct.

The hydrographer was depended upon to determine also, as closely as possible without actual survey, the acreage and kind of crops under each canal. He was also to endeavor to collect the information necessary to a reliable estimate of the yield of different crops and as to the effect of irrigation upon the soil, especially in regard to alkali, raising of the level of ground water, and as to whether drainage is necessary or advisable in certain cases.

MINATARE CANAL.

Taking the canals in their order downstream, the Minatare Canal is the first to be considered. This is the oldest of the canals embraced in the present discussion, having been first used in 1888.

Measurements of discharge were made as follows:

Date.	Gage.	Mean velocity.	Area of cross section.	Discharge.
	Feet.	*Feet per second.*	*Square feet*	*Cubic feet*
May 25	2.15	0.96		
June 21	2.65	1.77		

The fact that the less area of cross section occurs in connection with the greater discharge and height of water surface indicates that the canal has silted up considerably at the gaging section during the short period between gagings. This is a feature which seriously impairs the value of the record of gage heights as a basis for the estimate of the amount of water which flowed in the canal during the season. The record of gage heights covers the periods from May 25 to August 8, at which latter date the canal was shut down for the season. It was also shut down from June 30 to July 16. The record lacks … days of being complete. The gage heights ranged much of the time from 2.40 to 2.70 feet, the extreme range reported being from 1.80 to 2.80 feet.

On the basis of measurements and observations which have been collected it is estimated that 6,700 acre-feet flowed in the canal during the period from May 25 to August 8. The accompanying table (p. 150) shows that this canal supplied water for 4,542 acres of crops. The duty of water as measured at the gaging section corresponds, therefore, to the depth of 1.475 feet upon the land irrigated. It is worthy of note that nearly three-fourths of the acreage irrigated under this canal was in hay.

STEAMBOAT CANAL.

A gaging of this canal on June 6 showed that it was carrying 12.53 cubic feet per second. On September 21 the hydrographer noted that there was no discharge. The record of gage heights is too brief to be of any value. There are indications that the canal was shut down during much of the season. As noted in the table (p. 150), it carried water for only 320 acres of crops, more than three-fourths of which

It is to be noted that in the case of the two gagings by meter the less area of cross section occurs in connection with the earlier or greater discharge, this indicating that the canal had washed out to some extent during the summer. As noted in the case of the Minatare Canal, the effect of this is to impair the value of the record of gage heights for the purposes intended. The record of gage heights was one of the most faithful which was secured. It extends from June 6 to September 21. There is no record of the canal having been shut down during that period. Taking the record of gage heights in connection with the measured discharges, it is estimated that 6,600 acre-feet of water were carried in the canal during the period of record. As this was applied to 3,487 acres of crops, it indicates a duty of water corresponding to a depth of 1.89 feet over the irrigated area. The general tendency in the variation in the use of water seems to have been in the direction of using a uniformly decreasing amount as the season advanced, the rate of use in September being about half that in June.

NINE-MILE OR BAYARD CANAL.

The following tabulation sets forth the measurements of discharge which were made:

Date.	Gage.	Mean velocity.	Area of cross section.	Discharge.
	Feet.	*Feet per second.*	*Square feet.*	*Cubic feet per second.*
May 25	1.15	0.50	18.7	9.35
July 7	2.30	1.54	60.0	92.10
August 11	No rod.	....	....	34.69

There is no indication from these gagings that there was any material change in the bed of the canal during the interval between them. The record of gage heights was begun on May 25 and does not extend beyond July 17. It is estimated that 4,090 acre-feet of water flowed in the canal during this period. Three thousand one hundred and ninety acres were irrigated. This indicates that sufficient water flowed past the gaging section to cover the irrigated land to the depth of 1.28 feet. The actual amount which flowed during the season is, of course, considerably in excess of this, since the record is incomplete, as noted. The canal at a distance of 1,000 feet below the headgate has a nominal depth of 1½ feet, is 20 feet wide on the bottom, and has a grade of 2 feet per mile.

CHIMNEY ROCK CANAL.

Gagings were made as follows:

Date.	Gage.	Mean velocity.	Area of cross section.	Discharge.
	Feet.	*Feet per second.*	*Square feet.*	*Cubic feet per second.*
West branch:				
June 7	1.95	0.79	14.6	11.5
August 22	2.40	2.40	17.2	41.2
East branch:				
June 7	.50			
August 22	2.70	.70		4.8

Both of these sets of gagings show evidence of the canal being silted up at the gage to such an extent that a rating is out of the question. An estimate, however, based on these gagings and on the somewhat insufficient record of gage heights has been attempted with the following results:

About 6,000 acre-feet flowed in the canal between the dates June 7 and October 10, and was applied to 1,176 acres of crops. This would mean between 5 and 6 feet in depth of water on the area irrigated. This seems excessive, and, in view of the scantiness of the data on which it is based, can not be accepted as conclusive. The fact, however, that the period of time covered is longer than in some of the canals already discussed will account for some of the excess above the figures noted in connection with those canals.

ALLIANCE CANAL.

The hydrographer reports gagings as follows:

Date.	Gage.	Mean velocity.	Area of cross section.	Discharge.
	Feet.	*Feet per second.*	*Square feet.*	*Cubic feet per second.*
May 24	0.67	1.29	7.2	9.3
July 27	1.50	1.34	11.4	15.27
September 13	1.70			18.49

Here again it seems clear that the canal silted up to some extent during the period of record, and that a rating for direct application can not be entirely relied upon. However, it has been used, and results will be presented for later confirmation or disproof. In the case of this canal we have what would seem to be a complete and faithful record of gage heights from the beginning of the work on May 24 until August 24. From this record, in connection with the measurements of discharge, it is estimated that between the dates May 24 and October 1, 2,200 acre-feet of water passed the gaging section. Five hundred and sixty-eight acres were irrigated. This corresponds to an amount which would cover the irrigated a[illegible] 4 feet deep.

BELMONT CANAL.

While this is the largest canal among those under consideration, very little irrigation was attempted last year on the lands under it. Only 103 acres have been reported. Of course, an amount of water considerably in excess of that required to water this land passed down the ditch, but as the record book was lost by the observer, there is no basis for an estimate.

Empire, Schermerhorn, and H. T. Clarke are simply minor ditches, the small operations under which the hydrographer could not find it convenient to make note of.

The rainfall for the year 1899, as measured at the two gaging stations by the United States Weather Bureau observers, was as follows:

Precipitation at Gering and Camp Clarke, Nebr., 1899.

Month.	Gering.	Camp Clarke.	Month.	Gering.	Camp Clarke.
	Inches.	*Inches.*		*Inches.*	*Inches.*
January	[1] 0.80	0.80	August	2.24	2.12
February	1.04	.80	September	.19	Trace.
March	1.92	1.40	October	1.19	.74
April	.41	.53	November	.10	.30
May	7.72	2.75	December	.13	.15
June	1.77	1.53			
July	1.90	2.26	Total	19.41	13.38

[1] Record incomplete for this month.

The total precipitation for the months April to September, inclusive, at Gering was 14.23 inches. At Camp Clarke it was 9.19 inches.

The results of measurements of the canals are brought together in the following table:

Duty of water under canals from the North Platte River in Nebraska.

Canal.	Area irrigated.	Depth of water received.		
		Irrigation.	Rainfall.[1]	Total.
	Acres.	*Feet.*	*Feet.*	*Feet.*
Minatare Canal	4,542	1.475	0.98	2.455
Castle Rock Canal	3,487	1.89	.98	2.87
Nine Mile or Bayard Canal	3,190.5	1.28	.98	2.26
Chimney Rock Canal	1,176	5.10	.98	6.08
Alliance Canal	568	3.87	.98	4.85

[1] Mean of two stations from April to September, inclusive.

While it can not be claimed that the element of precision attaches to the work which has been discussed in the foregoing paragraphs, it seems that it may serve as a basis for a positive statement on one point. It has been a common custom in dealing with estimates of water supply and the duty of water in Nebraska to assume that, on the average, after the art of irrigation has been learned and the subsoil has absorbed its complement of water, a depth of 12 inches ...ether with the rainfall, will raise a crop. It is evi... practice has not been reached under these canals.

DUTY OF WATER UNDER GOTHENBURG CANAL.

(MAP, PLATE XL.)

Early in the season of 1899 it was arranged as a part of the regular work of the investigation[1] that records should be kept in connection with operations under the Gothenburg Canal in Dawson County, Nebr. By means of the standard apparatus of the investigation a record was obtained of the total amount of water entering the canal from June 7 to September 30, and of the amount applied on the farm of Mr. D. W. Daggett from June 19 to September 30. The main facts of interest relating to the plant are noted in the following letter, which was written under date of October 2, 1899, by Mr. C. A. Edwards, engineer of the canal:

The Gothenburg Water Power and Irrigation Company's canal is situated in the western part of Dawson County, and crosses the one hundredth meridian about 20 miles from its head. It was partly built in 1890 and 1891 and was completed in 1895, and is now 30 miles in length, with about 40 miles of laterals. The capacity of the irrigation portion is for 14,000 acres of land; the grade is 1 foot in 5,000 feet. We have watered this season a little over 6,000 acres of land, 2,400 being small grain, 3,400 corn, and about 200 acres of alfalfa, and the remainder grain, etc.

The yield under the ditch has run from 7 to 30 bushels of wheat this season. Where the wheat was a poor crop I would say that it was damaged by the Hessian fly. The corn crop will average from 50 to 70 bushels per acre.

The amount of water delivered from the main canal is shown by the register sheets which we have sent you weekly. At Mr. Daggett's the register did not work satisfactorily, but we have missed only one week while the water was running—September 16 to 23—and the amount that week was equal to the amount from the 23d to the 30th, which we have given you in miner's inches.

Mr. Daggett had in 35 acres of winter wheat, the yield of which was 25 bushels per acre, and 25 acres of corn, the yield of which was 65 bushels per acre. This was all the crop that was watered by water running through the measuring weir.

There was one party who sowed 7 acres of buckwheat and thrashed out 154 bushels of grain, for which he received 75 cents per bushel.

Alfalfa does very well here, cutting 1½ to 2 tons at each cutting and three to four cuttings per season. Corn is the staple crop. Wheat is worth here in the market from 50 to 55 cents per bushel, and corn from 15 to 20 cents per bushel.

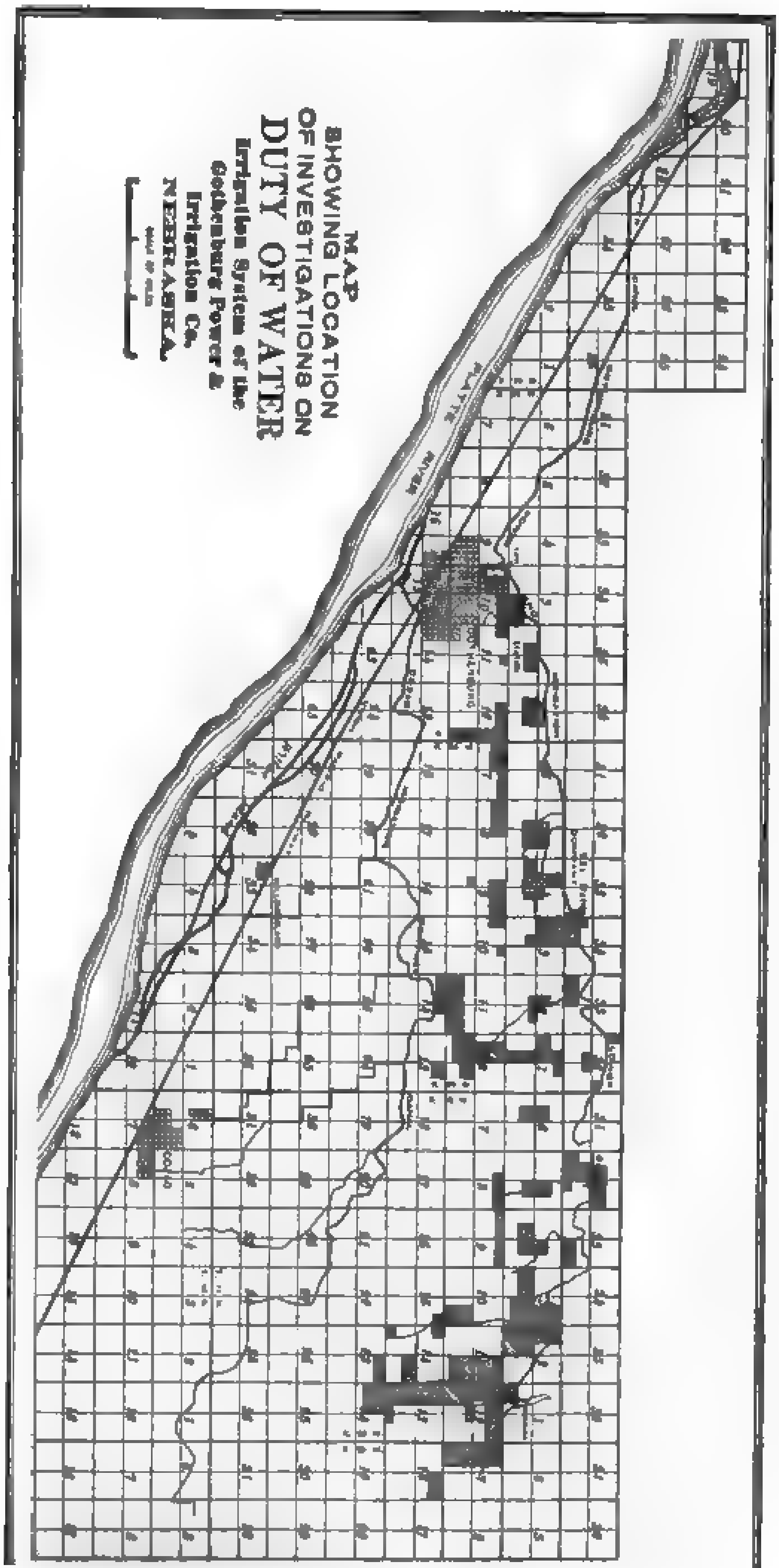
The people under our canal seem to be very well satisfied with the water furnished them. We deliver about 2 cubic feet per second of water to each patron and not less, whether he has a small water right or not, limiting the time rather than the flow of water. We find this a great deal more satisfactory than to deliver one-half cubic foot per second on 40 acres. It is better for the farmer and the ditch company also, as a large stream will cover more ground than a small stream running full time.

The subjoined tabulations set forth the results obtained:

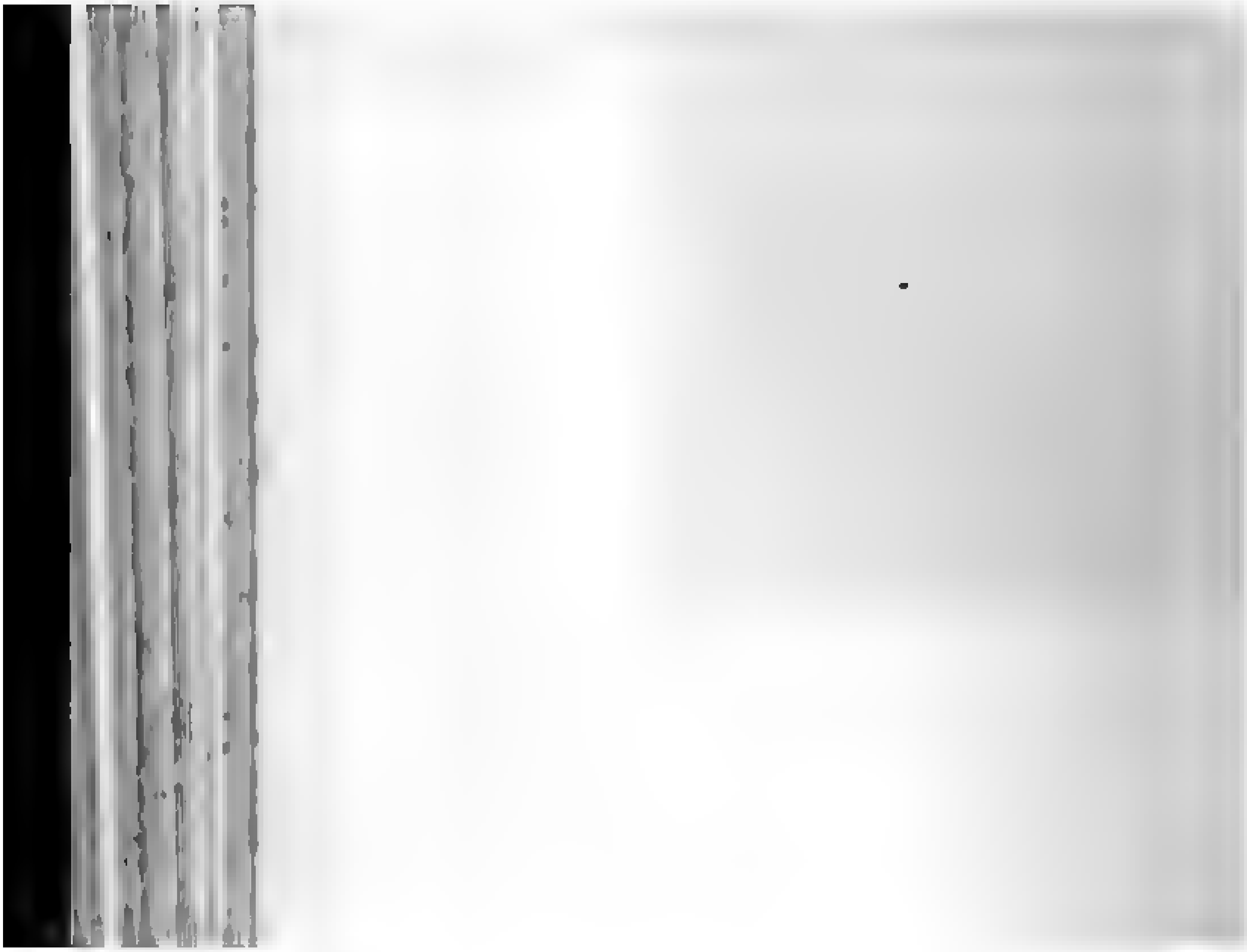
Monthly precipitation at Gothenburg, Nebr., 1899.

	Inches.		Inches.
April	0.41	August	1.93
May	4.01	September	.60
June	2.16	Total	10.19
July	1.08		

[1] Office of Experiment Stations, United States Department of Agriculture.



MAP OF THE IRRIGATION SYSTEM OF THE GOTHENBURG POWER AND IRRIGATION COMPANY, NEBRASKA.



Water discharged by the Gothenburg Canal, June 7 to September 30, 1899.

[See diagram, Pl. XX, p. 76.]

Day.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	193.2618	133.2049	153.1667
2	....	181.9910	112.2315	150.0804
3	....	182.5689	137.3816	145.9771
4	....	162.3893	161.4043	140.8587
5	....	169.2397	142.2251	112.5981
6	....	204.2938	127.9279	107.2158
7	70.0753	147.3078	118.5133	75.6788
8	131.2460	84.8298	70.0714	64.4591
9	41.1236	97.5966	59.4027	95.3960
10	32.8073	134.2545	12.8339	113.3629
11	145.8275	159.1402	....	98.6471
12	147.9195	185.1098	....	80.2601
13	145.1559	184.5293	....	75.9543
14	141.4441	201.4008	....	94.2995
15	134.8146	199.7245	....	95.7359
16	142.6964	200.3585	10.7671	117.7786
17	148.0958	192.3830	73.3322	125.8655
18	155.5624	185.7055	70.0954	156.3031
19	155.0055	197.7352	....	173.0666
20	167.0403	209.0522	....	121.3553
21	173.2836	213.5207	116.9668	53.7272
22	186.9791	216.9674	126.6240	131.2451
23	185.9046	220.8303	138.8584	138.2376
24	185.6171	221.7937	142.4916	119.9843
25	179.1158	216.1476	140.8279	109.1212
26	198.2978	189.9424	142.2493	95.4941
27	187.0730	188.7925	171.5542	77.3916
28	188.4005	167.0458	173.0200	77.8337
29	197.3041	176.0797	173.5845	85.2397
30	202.0668	166.7813	170.6236	113.0327
31	....	162.6209	149.9008	....
Total	3,642.8566	5,613.3945	2,876.0924	3,299.3668

Duty of water under Gothenburg Canal.

Area irrigated	acres..	6,000
Water used	acre-feet..	15,431.7103
Depth of irrigation	feet..	2.57
Depth of rainfall	do...	.85
Total depth of water received by land	do...	3.42

Water used on the farm of D. W. Daggett, near Gothenburg, Nebr., June 19 to September 30, 1899.

[See diagram, Pl. XXI, p. 76.]

Day.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	0	0	2.5825
2	....	0	0	2.8419
3	....	0	0	2.8971
4	....	0	0	2.6415
5	....	4.5804	0	.5206
6	....	5.7468	0	.0750
7	....	5.4480	0	0
8	....	4.1520	0	0
9	....	.2563	0	5.4742
10	....	.0044	0	5.8137
11	....	.0432	0	4.6743
12	....	.0521	0	3.3601
13	....	.0684	0	2.0284
14	....	.0476	0	1.8311
15	....	.0135	0	3.1128
16	....	0	0	3.4700

27.	0	1.[illegible]	2.470
28.	0	0	2.727
29.	0	0	2.441
30.	0	0	2.22[illegible]
31.		0	2.276
Total	25.[illegible]	44.[illegible]	[illegible]

a Estimated. See letter of October 2, 1909, from C. A. Edwards.

Duty of water on farm of D. W. Daggett.

Area irrigated .... acres..	60
Water used .... acre-feet..	148.
Depth of irrigation .... feet..	2.
Depth of rainfall .... do...	.
Total depth of water received by land .... do...	3.

It is to be noted that there was little difference between th
of water applied on the Daggett farm and the average amou
to all lands under the canal. This slight difference is some
prising when it is remembered that the duty of water as note
canal is what may be termed the headgate duty, and included
seepage and evaporation from the canal, together with such
there may be from the lower ends of the laterals. It indicate
losses from seepage are much less than frequently exist.

The work in the North Platte Valley viewed in the light of
precise work seems to present no especially abnormal featur

COLORADO.

DUTY OF WATER UNDER THE AMITY CANAL.

By Special Agent THOMAS BERRY,
Chief Engineer of the Great Plains Water Company.

LOCATION AND DESCRIPTION OF CANAL SYSTEM.

The use of water described in this report occurred under the canal system of the Great Plains Water Company, located in the Arkansas Valley, on the north side of the river in Otero, Bent, Kiowa, and Prowers counties, Colorado, and in Hamilton County, Kansas. It comprises the Amity and Buffalo canals, and a storage system from which a supplementary supply for these canals is derived and lands above them may be irrigated. The accompanying map (Pl. XLI) shows the extent of the system in Colorado.

The development of the reservoir system is a result of the uncertainty that the river will provide an adequate direct supply for the Amity Canal, and may be considered an independent project.

AMITY CANAL.

In Colorado the service of the Amity Canal is confined to Prowers County, and in Kansas to Hamilton County. It has a capacity of 740 cubic feet per second at the headgates and 177 cubic feet per second at the State line. The maximum and minimum grades are, respectively, 1.584 feet per mile and 1.056 feet per mile.

The width of the bottom varies from 32 feet at the headgates to 16 feet at the State line and 14 feet at the terminus, and the heights above grade to which water is run at these points are 6 feet, 3.5 feet, and 3 feet, respectively. The slopes of the standard embankment throughout are 1 on 2 on the water side, and 1 on 1.5 on the outer side; the minimum width on the top is 8 feet, and the height above high-water mark is 1.5 feet. All embankments over 6 feet in height at crossings of "draws" (dry ravines), creeks, and arroyos have slopes of 1 on 3 on the water side and 1 on 1.5 on the outer side, and are not less than 12 feet wide on the top, which i[illegible] high-water mark. The excavation on the upper sid[illegible] of 1 on 1.

The construction of the canal was commenced in the spring of 1 but the work which brought the property to its present stat development did not begin until the spring of 1893. Until the la year the canal depended altogether upon sand and brush dams for diversion of its supply from the river, a condition which in itself sufficient to hinder the progress of agricultural improvement advancement. That year a pile and frame dam and new headg were built, and early in 1895 work on the enlargement and exten of the canal was commenced.

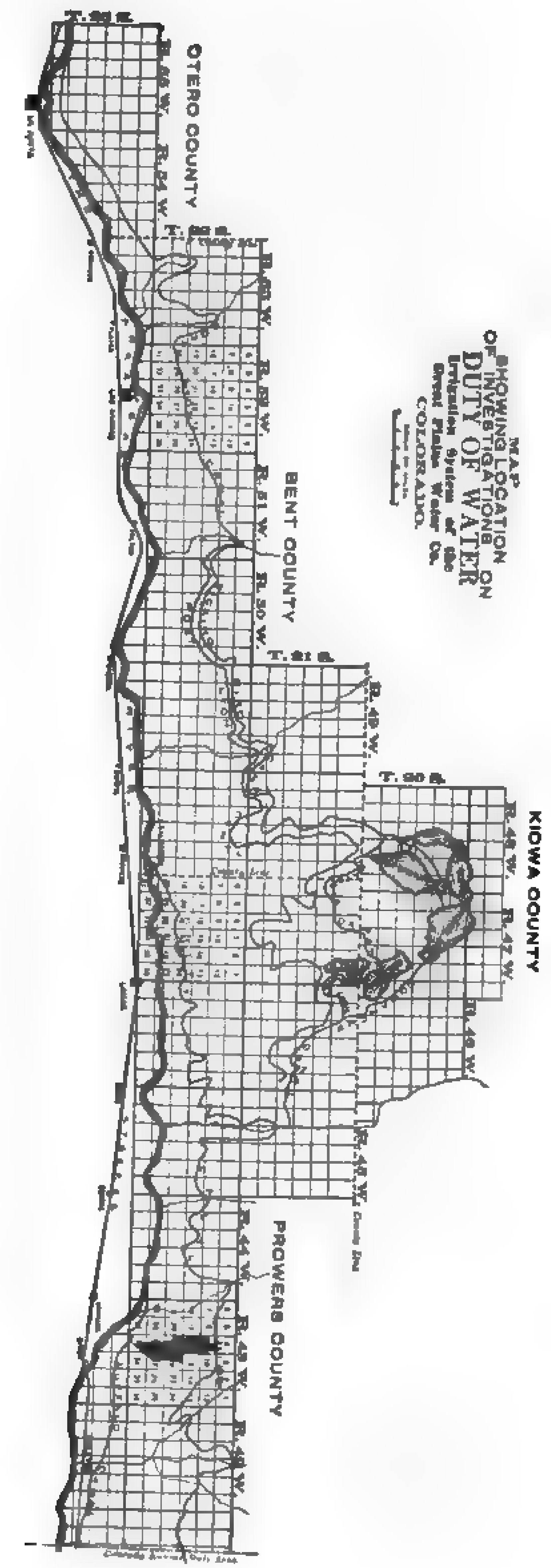
Sand traps in combination with check and waste gates are bui the canal at a point 3,000 feet from the headgates. To maintain priorities of the canals lower on the river, there is always suffic water turned out at this point to carry the sand coming in at the h gates back to the river, so that no trouble is experienced with the canal.

Other structures and appurtenances of the canal are a measu flume; check and waste gates at Big Sandy Creek; waste gate Buffalo Creek; and check and waste gates at Cheyenne Creek; lateral gates and bridges.

All lateral gates are constructed of lumber, and those for i vidual water rights are furnished with double valves arranged so the water can be cut off by the user, but increased, the head rem ing constant, only by the patrolman.

There is not a flume in the length of the Amity Canal, the wa ways all being crossed by means of fills. Spillways are gener provided in favorable locations at each end of the embankment an a safe distance therefrom by keeping construction down to the hi water line of the canal. This, of course, can be only a partial rem of the danger at such points, and while the method of construc may be economical at those creeks which are crossed nearly on a le it is very doubtful, everything considered, if it is so at the dee crossings. Usually the cost per cubic yard of moving materia such times as breaks occur is very high; in fact it may always be c sidered a maximum one, and each succeding break is more expens to repair than its predecessor, from the fact that the point fr which material can be obtained keeps receding.

Except for the creeks and their "breaks," which are confined narrow margins on either side, the surface of the country watered the Amity Canal is smooth and unbroken. The high land betw the main drainage ways as a general rule slopes unbrokenly and u formly either way to the drainage, while the slope to the south on summit is always irregular, one or more points inaccessible to wa intervening between the canal and the "bluffs" which bound the ri bottom lands. The slope of the country from the north toward river is about 20 feet per mile.



MAP OF THE IRRIGATION SYSTEM OF THE GREAT PLAINS WATER COMPANY, COLORADO.

The main laterals are constructed by the company and afterwards incorporated and turned over, for management, operation, and maintenance, to the owners of the lands which are watered from them. Their capacities run from 3 cubic feet per second for individual rights to 67 cubic feet per second for the larger laterals. The same care that governed the construction of the main canal was and is being used in the construction of the main laterals. They are all built on uniform grades, and where the country is steep, excess slope is overcome by the introduction of wooden drops.

The Amity Canal is in irrigation district No. 67 and has an appropriation of 283.5 cubic feet per second, dating from February 21, 1887.

BUFFALO CANAL.

The Buffalo Canal heads north of the town of Granada, and is located along the base of the steep slopes which divide the "bench" land from the bottom land, having a length of 16 miles in the State line. It has a grade of 5.28 feet per mile and a capacity of 215 cubic feet per second. By reason of its location accidents to this canal are numerous during the rainy season, and the cost of maintaining it is very high.

It is in irrigation district No. 67 and has an appropriation of 67.5 cubic feet per second, dating from January 29, 1885.

RESERVOIR SYSTEM.

The reservoir system consists of the King, Neeskah (Queen), Neenoshe, Neegronda, and Neesopah reservoirs; a right of way through the Fort Lycn Canal from the headgates to Gageby Arroyo (Pl. XLII, fig. 1), a distance of 42 miles; Kicking Bird, Satanta, and Lone Wolf, all supply canals; and the Comanche and Pawnee, both outlet canals. The Fort Lyon Canal and the Kicking Bird Canal are the main feeders, and their capacities are, respectively, 1,700 and 1,000 cubic feet per second. The grade of the former varies from 1.584 feet per mile to 2.112 feet per mile, and for a short distance through rock on the west side of Horse Creek it has a fall of 5.28 feet per mile. The Kicking Bird Canal has a uniform grade of 1.056 feet per mile, except on 2.5 miles, which fall at the rate of 0.75 feet per mile.

The Lone Wolf and Satanta canals are independent feeders to Neenoshe and Neeskah reservoirs, and are diverted from the main canal 0.75 mile and 1.5 miles, respectively, from its terminus.

The Lone Wolf Canal is 4 miles long and has a capacity of 700 cubic feet per second. Check gates are constructed at its head across the Kicking Bird Canal for the better control of the division of the water for all three canals.

The Satanta Canal is 14.5 miles long and has a capacity of 350 cubic feet per

The reservoirs are five in number, with capacities as follows:

Capacities of reservoirs.

Name.	Area at high-water mark.	Capacity.
	Acres.	*Acre-feet.*
No. 1, King	1,282	16,279
No. 2, Queen (Neeskah)	1,980	22,046
No. 3, Neenoshe	3,777	60,696
No. 4, Neegronda	3,490	57,209
No. 5, Neesopah	3,600	26,464
	14,129	182,694

INVESTIGATIONS IN 1899.

The plans for the observation of the duty of water under the Amity Canal during the past season have been only partially carried out, owing to the failure of one of the instruments for measuring the flow of water. One of the instruments was placed in Biles Lateral and has worked successfully. A record was also kept of the land irrigated under this lateral, so that the returns from that station are complete. Some difficulty was experienced in finding a suitable location for the other instrument. Finally an 80-acre tract was found, the owner of which was very much interested in the work and anxious to do all he could to further the investigations. A flume and register were put in his lateral, but for some reason the clock would not work. It was taken out and repaired, but again failed to work, so that there are no returns for that lateral.

DUTY OF WATER UNDER AMITY CANAL.

A record is kept by the company of the water entering the Amity Canal at its headgate, and also of the acreage irrigated under the whole system. These measurements are less accurate than those kept for the smaller area under Biles Lateral, and the distance from the headgate to the land irrigated introduces another element of uncertainty, since there are no records of the losses from the canal from seepage and evaporation. The results of these measurements are given below.

FIG. 1.—WASTEWAY AND GAGEBY ARROYO, GREAT PLAINS WATER COMPANY.

FIG. 2.—OUTLET CONDUIT NO. 2, GREAT PLAINS WATER COMPANY.

Water discharged by the Gothenburg Canal, June 7 to September 30, 1899.

[See diagram, Pl. XX, p. 76.]

Day.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	193.2618	133.2049	153.1667
2	....	181.9910	112.2315	150.0804
3	....	182.5689	137.3816	145.9771
4	....	162.3893	161.4043	140.8587
5	....	169.2397	142.2251	112.5981
6	....	204.2938	127.9279	107.2158
7	70.0753	147.3078	118.5133	75.6788
8	131.2460	84.8298	70.0714	64.4591
9	41.1236	97.5966	59.4027	95.3960
10	32.8073	134.2545	12.8339	113.3629
11	145.8275	159.1402	....	98.6471
12	147.9195	185.1098	....	80.2601
13	145.1559	184.5293	....	75.9543
14	141.4441	201.4008	....	94.2995
15	134.8146	199.7245	....	95.7359
16	142.6964	200.3585	10.7671	117.7786
17	148.0958	192.3830	73.3322	125.8655
18	155.5624	185.7055	70.0954	156.3031
19	155.0055	197.7352	....	173.0666
20	167.0403	209.0522	....	121.3553
21	173.2836	213.5207	116.9668	53.7272
22	186.9791	216.9674	126.6240	131.2451
23	185.9046	220.8303	138.8584	138.2376
24	185.6171	221.7937	142.4916	119.9843
25	179.1158	216.1476	140.8279	109.1212
26	198.2978	189.9424	142.2493	95.4941
27	187.0730	188.7925	171.5542	77.3916
28	188.4005	167.0458	173.0200	77.8337
29	197.3041	176.0797	173.5845	85.2397
30	202.0668	166.7813	170.6236	113.0327
31	....	162.6209	149.9008	....
Total	3,642.8566	5,613.3945	2,876.0924	3,299.3668

Duty of water under Gothenburg Canal.

Area irrigated	acres..	6,000
Water used	acre-feet..	15,431.7103
Depth of irrigation	feet..	2.57
Depth of rainfall	do...	.85
Total depth of water received by land	do...	3.42

Water used on the farm of D. W. Daggett, near Gothenburg, Nebr., June 19 to September 30, 1899.

[See diagram, Pl. XXI, p. 76.]

Day.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	0	0	2.5825
2	....	0	0	2.8419
3	....	0	0	2.8971
4	....	0	0	2.6415
5	....	4.5804	0	.5206
6	....	5.7468	0	.0750
7	....	5.4480	0	0
8	....	4.1520	0	0
9	....	.2563	0	5.4742
10	....	.0044	0	5.8137
11	....	.0432	0	4.6743
12	....	.0521	0	3.3601
13	....	.0684	0	2.0284
14	....	.0476	0	1.8311
15	....	.0135	0	[illegible]
16	....	0	0	[illegible]

The acreage of the various crops cultivated under the Amity Canal during the season of 1899 was as follows:

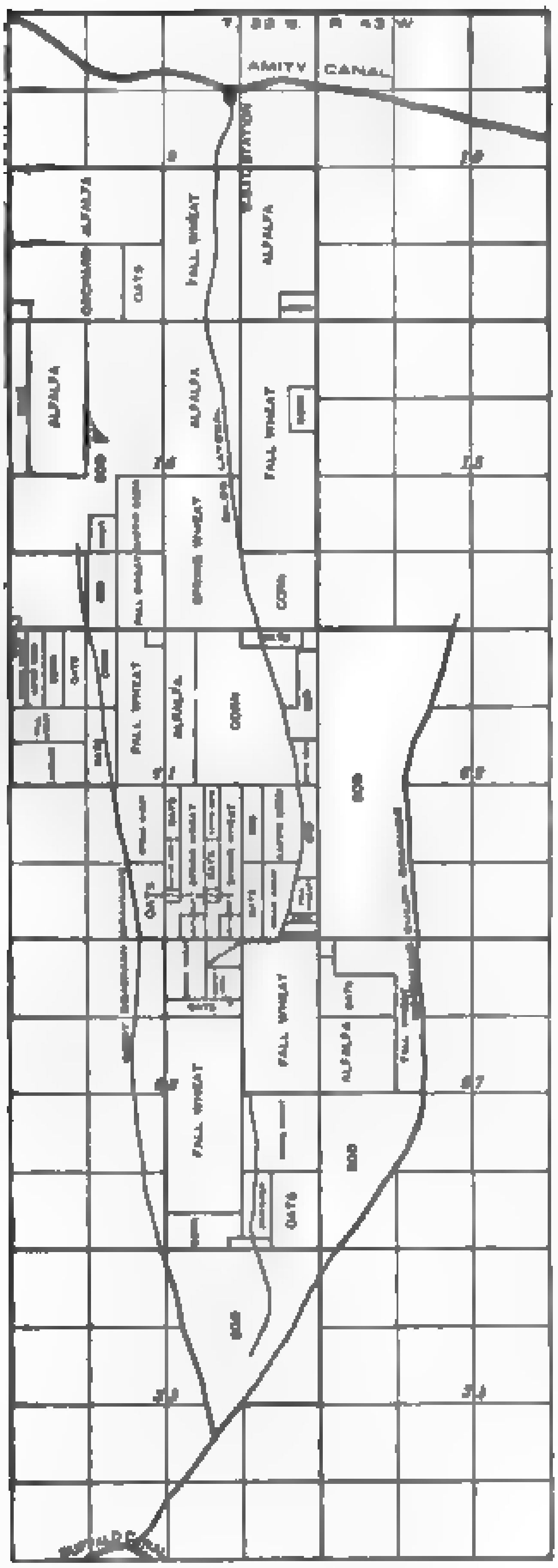


Fig. 14.—Map of Biles Lateral.

Acreage irrigated under Amity Canal, 1899.

	Acres.
Fall wheat	3,111
Spring wheat	1,153
Oats	2,071
Barley	279
Corn	1,979
Cane, etc	993
Alfalfa	4,755
Flax	355
Broom corn	175
Cantaloupes	376
Orchard	271
Millet	207
Garden	71
Total	15,796

From the above tables we have the following summary showing the duty of water under the Amity Canal for the season of 1899:

Duty of water under Amity Canal, 1899.

Total discharge of canal, 1899, to October 1 ....acre-feet..	77,765
Acreage irrigated ....acres..	15,796
Depth of irrigation ....feet..	4.92
Depth of rainfall at Lamar..do...	.91
Total depth of water received by land....feet..	5.83

This, of course, makes no allowance for loss of water between the headgates and the place of use. In a canal having as great length as the Amity Canal the loss from both seepage and evaporation is necessarily large, so that the land received much less water than is indicated in the table.

Expressed in the usual way, the above results show a duty of about 80 acres per cubic foot per second for the season of 194 days from March 20 to October 1, during which the water ran.

COLORADO.

DUTY OF WATER UNDER THE AMITY CANAL.

By Special Agent THOMAS BERRY,
Chief Engineer of the Great Plains Water Company.

LOCATION AND DESCRIPTION OF CANAL SYSTEM.

The use of water described in this report occurred under the canal system of the Great Plains Water Company, located in the Arkansas Valley, on the north side of the river in Otero, Bent, Kiowa, and Prowers counties, Colorado, and in Hamilton County, Kansas. It comprises the Amity and Buffalo canals, and a storage system from which a supplementary supply for these canals is derived and lands above them may be irrigated. The accompanying map (Pl. XLI) shows the extent of the system in Colorado.

The development of the reservoir system is a result of the uncertainty that the river will provide an adequate direct supply for the Amity Canal, and may be considered an independent project.

AMITY CANAL.

In Colorado the service of the Amity Canal is confined to Prowers County, and in Kansas to Hamilton County. It has a capacity of 740 cubic feet per second at the headgates and 177 cubic feet per second at the State line. The maximum and minimum grades are, respectively, 1.584 feet per mile and 1.056 feet per mile.

The width of the bottom varies from 32 feet at the headgates to 16 feet at the State line and 14 feet at the terminus, and the heights above grade to which water is run at these points are 6 feet, 3.5 feet, and 3 feet, respectively. The slopes of the standard embankment throughout are 1 on 2 on the water side, and 1 on 1.5 on the outer side; the minimum width on the top is 8 feet, and the height above high-water mark is 1.5 feet. All embankments over 6 feet in height at crossings of "draws" (dry ravines), creeks, and arroyos have slopes of 1 on 3 on the water side and 1 on 1.5 on the outer side, and are not less than 12 feet wide on the top, which is 3 feet above high-water mark. The excavation on the upper side is cut down to a slope of 1 on 1.

A very careful record was kept of all the land irrigated under this lateral. The areas devoted to the various crops are shown on the map (fig. 14). The following table gives the acreage:

Acreage irrigated under Biles Lateral, 1899.

	Acres.		Acres.
Fall wheat	518	Garden	31
Spring wheat	211	Orchard	79
Alfalfa	387	Millet	6
Oats	152	Cantaloupes	21
Kafir corn	70.5	Sod	204
Indian corn	141		
Cane	56.5	Total	1,884

From the above tables the following summary of duty under Biles lateral is obtained:

Duty of water under Biles Lateral, 1899.

Discharge of lateral	acre-feet	3,430.2
Area irrigated	acres	1,884
Depth of irrigation	feet	1.8207
Depth of rainfall	do	.6850
Total depth of water received by land	do	2.5057

The length of season from the first to the last irrigation is 160 days. For that length of season the duty of 1 cubic foot per second is about 175 acres.

LOSS OF WATER.

The preceding tables show that the water discharged by the Amity Canal at its headgates would cover the land irrigated to a depth of 4.92 feet, provided it all reached the land. The depth of irrigation under Biles Lateral is 1.82, showing a loss of 63 per cent of the water between the headgates and the laterals, supposing that Biles Lateral correctly represents the whole system.

However, this lateral does not fairly represent an average of the whole system, so that the loss is something less than the 63 per cent shown by comparing the quantity of water passing the headgates and that used under Biles Lateral.

The tables given indicate a low duty under the Amity Canal. No doubt the duty this year is much lower than it has been in previous years on account of weather conditions alone. The seepage in the early part of the season all along the canal was much greater than has ever before been observed, a result, no doubt, of the excessive frosts of last winter. While the high winds usually blow during the months of March, April, and May, they commenced this year a month later and continued on through June. The comparative effect of this alone upon evaporation was very apparent.

As a whole, the character of the soil and the configuration of the land under the Amity Canal are favorable to a high duty. The temporary conditions which are unfavorable to a high duty are the short time the land has been irrigated, the inexperience of the irrigators, and to some extent the manner in which the water is conveyed to the land. It is safe to say that 75 per cent of the land has been under cultivation not more than three years, and 50 per cent of the whole not over two years. Our settlers are mostly Eastern people who never saw irrigation until they came to Colorado.

In so far as an economical delivery of the water is concerned, we are doing all we can to eliminate the individual lateral and discouraging the desire for such among farmers. The company builds the main laterals and turns them over, for operation and maintenance, to the communities owning the land which they cover. These laterals are very carefully aligned and constructed, and the conveyance of water through them and its distribution are perhaps as economical as they could well be under the circumstances.

It is expected that measuring flumes will be put in at the heads of all main laterals between now and next season. This will not be done with the intention of limiting the farmer to the amount of water he is actually entitled to, but because it will have a tendency toward careful application and economy on his part, and generally because it will be an aid in the transition from the extravagant use of as much as he can handle to the established duty of 2 acre-feet delivered at the headgates of the main laterals.

CROP YIELDS.

The following table, showing the yields of crops under the Amity Canal, was very carefully compiled and may be considered thoroughly reliable. As shown by this table this season's crops were not a success, and the value of the returns of duty of water is somewhat lessened by this fact. The yields were as follows:

Acreage irrigated and crop yields under Amity Canal, 1899.

Crop.	Acreage.	Total yield.	Yield per acre.
	Acres.		
Fall wheat	3,111	20,895 bushels	6.75 bushels.
Spring wheat	1,153	6,259 bushels	5.50 bushels.
Oats	2,071	34,569 bushels	16.75 bushels.
Barley	279	3,042 bushels	11 bushels.
Corn	1,979	12,110 bushels	6 bushels.
Cane, etc	993	1,386 tons	1.50 tons.
Alfalfa	4,755	11,686 tons	2.50 tons.
Flax	355	2,232 bushels	6 bushels.
Broom corn	175	43 tons	0.25 tons.
Cantaloupes	376	12,567 crates	33 crates.
Orchard	271		
Millet	207		
Garden	71		
Total	15,796		

PRECIPITATION, EVAPORATION, AND TEMPERATURE.

The following tables give the precipitation at two points in the Arkansas Valley, on the Amity Canal, and the evaporation and temperature each at one station:

Precipitation, Lamar Station, 1899.

Day.	May.	June.	July.	August.	September.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1					
2					
3					
4					
5	1.17			1.60	
6				.50	
7				.10	
8					
9	.34	0.08			0.72
10					
11					
12					
13			0.09	.20	
14			2.30		.30
15			.10		.10
16		.80			.10
17					
18	.36				
19			2.27		
20					
21					
22		.35			
23		.30	.76		
24					
25	.52				
26					
27					
28			.45		
29					
30					
31					
Total	2.39	1.53	5.97	2.40	1.22

There were high winds at Lamar on May 1, 2, 12, 13, 14, 15, 17, 18, 20, 24, 25, and 29, and on September 4, 5, 13, and 27. Thunderstorms occurred on May 18 and 25.

Precipitation and evaporation, Holly Station, 1899.

Day.	June.		July.		August.		September.	
	Precipitation.	Evaporation.[1]	Precipitation.	Evaporation.	Precipitation.	Evaporation.	Precipitation.	Evaporation.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1								
2			0.03					
3			.15					
4			.03	1.89	2.15	1.98		1.82
5					.19			
6					.12			
7	0.04							
8	.45							
9	.02						0.80	
10								
11				1.57	.02	1.44		.88
12			.05					
13			.20					
14					.10			
15			.53				.03	
16		2.28					.30	
17					.37			
18						1.57		.90
19			.16	1.84				
20								
21	.05							
22	.80							
23	.07	2.10	.15					
24	.10							
25								
26						2.04		1.68
27				1.63				
28		1.08	.15					
29			.08					
30			.08					
31								
Total	1.53	5.46	2.61	6.93	2.95	7.03	1.13	4.73

[1] Evaporation measurements not begun until June 13.

There were high winds at Holly from August 15 to 22, and some heavy dews from September 8 to 15.

Temperature at Lamar, 1899.

	May.	June.	July.	August.	September.
	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
Maximum	95.0	106.0	105.0	106.0	106.0
Minimum	31.0	45.0	55.0	49.0	38.0
Mean maximum	81.7	91.0	90.0	95.7	88.4
Mean minimum	48.0	57.0	62.0	62.0	51.5
Mean	65.0	74.0	76.0	79.0	70.0

DISCHARGE OF THE ARKANSAS RIVER AT PUEBLO, COLO.

Comparative table of discharge of the Arkansas River at Pueblo, Colo., for the irrigatio[n] seasons of 1895, 1896, 1897, and 1898.

Month.	Stage of water.	1895.	1896.	1897.	1898.
		Cubic feet per second.	*Cubic feet per second.*	*Cubic feet per second.*	*Cubic fee[t] per secon[d].*
April	Maximum	1,790	1,172	616	[illegible]
	Mean	744	470	285	[illegible]
	Minimum	301	276	146	[illegible]
May	Maximum	2,490	2,852	3,470	[illegible]
	Mean	1,561	1,097	1,631	[illegible]
	Minimum	601	472	578	[illegible]
June	Maximum	3,564	2,096	3,750	[illegible]
	Mean	2,152	896	2,214	[illegible]
	Minimum	1,455	412	1,218	[illegible]
July	Maximum	5,000	2,885	1,848	[illegible]
	Mean	1,900	688	1,086	[illegible]
	Minimum	1,044	301	474	[illegible]
August	Maximum	3,112	3,438	1,170	[illegible]
	Mean	1,275	489	470	[illegible]
	Minimum	568	208	180	[illegible]
September	Maximum	888	441	436	[illegible]
	Mean	494	309	272	[illegible]
	Minimum	383	219	146	[illegible]

WYOMING.

DUTY OF WATER IN WYOMING.

By C. T. Johnston.
Assistant in Irrigation Investigations.

The investigation of the duty of water in Wyoming for the season of 1899 was limited to the lands of the Wyoming Development Company, at Wheatland.[1] The irrigable land under this system has a total area of 60,000 acres, and is located 90 miles north of the southern boundary of Wyoming and 35 west of the eastern boundary of that State. It is east of the Laramie Mountains, and has a mean elevation of 4,800 feet. The soil is a sandy loam and quite uniform. Water is obtained from the Laramie River, and the supply is made secure by a complete reservoir system under construction having a total capacity of 90,000 acre-feet. Irrigation seldom begins before June 20, and the greatest demand for water is felt between that date and July 15. Unfortunately, the flood discharge of the Laramie River takes place between May 15 and June 10, while the transition from high water to low water is often rapid, taking place at times in a week or ten days; hence the necessity for storage. The distributing system is shown on the accompanying map (Pl. XLIII).

In the investigation for the season of 1899, a continuous record was kept of the depth of the water flowing in Canal No. 2 by means of a Wyoming nilometer. The use of a weir being impossible, a flume at the sand gate, a short distance below the headgate, was rated, and the register installed at this place. Canal No. 2 is supplied during low water by a ditch which carries water from Reservoir No. 2. This ditch joins the canal just above the sand gate, hence all the water used passed through that structure.

The duty of water as determined by these measurements is about half what would have been obtained if the water wasted through laterals and at the end of the canal could be taken into account, and if the loss due to evaporation and seepage could be eliminated. The

[1] For a fuller discussion of the use of water in irrigation in Wyoming, see U. S. Dept. Agr., Office of Experiment Stations Bul. 81.

following table gives the discharge of Canal No. 2 during the time that irrigation was necessary:

Flow of Canal No. 2, Wyoming Development Company, Wheatland, Wyo., season of 1899.

[See diagram, Pl. XXII, p. 78.]

Day.	June.	July.	August.	Day.	June.	July.	August.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*		*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		331.06	348.01	18	210.67	287.69	
2		331.06	351.28	19	210.67	264.18	
3		326.70	348.01	20	210.67	236.01	
4		331.06	325.51	21	210.67	210.67	
5		331.06	244.76	22	214.52	210.67	
6		331.06	255.40	23	246.71	210.67	
7		331.06	335.49	24	258.19	210.67	
8		331.06	335.49	25	260.16	210.67	
9		331.06		26	264.13	239.56	
10		331.06		27	258.19	266.33	
11		331.06		28	326.70	351.28	
12	210.67	331.06		29	331.06	357.91	
13	210.67	331.06		30	326.70	357.91	
14	210.67	331.06		31		351.28	
15	210.67	331.06					
16	210.67	280.66		Total	4,593.06	9,295.34	2,543.95
17	210.67	287.69					

Monthly precipitation at Wheatland, Wyo., 1899.

	Inches.
June	2.63
July	1.28
August	.49
	4.40

The facts obtained are shown as follows in tabular form:

Duty of water under Canal No. 2, 1899.

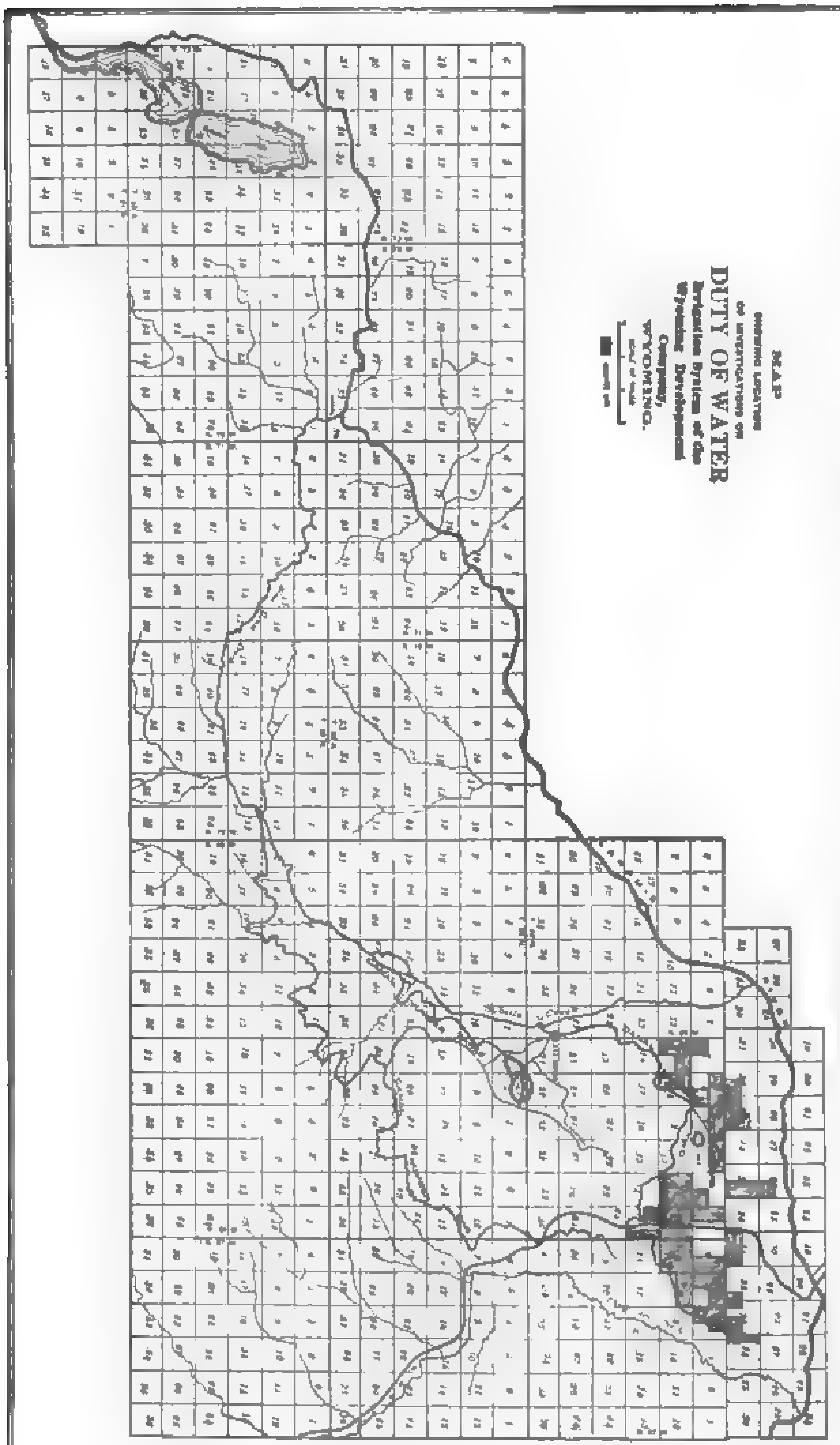
Area irrigated	acres..	6,502.00
Water used	acre-feet..	16,432.35
Depth of irrigation	feet..	2.53
Rainfall for June, July, and August	do...	.37
Total depth of water received	do...	2.90

Table showing acreage and yields of each crop.

Crop.	Acres.	Total yield.	Yield per acre.
Wheat	2,292	49,000 bushels.	21.4 bushels.
Oats	1,398	51,500 bushels.	41.1 bushels.
Corn	800	20,000 bushels.	25 bushels.
Potatoes	350	24,500 bushels.	70 bushels.
Hay	1,662	6,975 tons.	4.2 tons.

A second investigation was carried on to determine the quantity of water needed for different crops. Only corn and oats were grown on the area included in this work.

During the first week of June, 1899, two weirs were constructed to measure the water used on a farm a few miles west of the town of



MAP OF IRRIGATION SYSTEM OF WYOMING DEVELOPMENT COMPANY, WYOMING.

Wheatland. As the two crops were irrigated at different times, one register served for both, being shifted from one weir to the other as water was used. The oats had an area of 15 acres, and the ground on which they were grown was not broken until the spring of that year. The field of corn had an area of 20 acres. Both of these crops were carefully irrigated, only the water needed being used.

The following tables show the quantity of water used and the dates when irrigation took place:

Table showing volume of water used in irrigation of oats.

[See diagram, fig. 12, p. 79.]

	Acre-feet.		Acre-feet.
June 13	0.94	July 14	3.38
June 14	2.70	July 15	2.56
June 15	2.13	July 19	2.93
June 16	2.48	July 20	2.89
June 17	.42	July 21	1.44
	8.67		14.60
July 13	1.40	Total	23.27

Table showing the volume of water used in irrigation of corn.

[See diagram, fig. 13, p. 80.]

	Acre-feet.		Acre-feet.
July 24	2.14	July 28	2.30
July 25	2.46	July 29	1.26
July 26	2.73		
July 27	3.12	Total	14.01

From these two tables the duty of water for each crop has been computed.

Duty of water on oats and corn at Wheatland, Wyo., 1899.

	Oats.	Corn.
Area irrigated ... acres	15	20
Water used ... acre-feet	23.27	14.01
Depth of irrigation ... feet	1.55	.70
Rainfall for June, July, and August ... foot	.37	.37
Total depth of water received ... feet	1.92	1.07

It will be noticed that the general duty of water under the canal is much less than that under the lateral. The difference is almost entirely due to the loss of water from the canal through seepage and evaporation.

The total length of the canal is 22 miles and the mean length between the point where the measurements are kept and the extreme eastern tract irrigated is about 10 miles. The loss of water due to seepage in the first 2 miles of the canal below the sand gates is excessive. The

canal follows a steep sidehill for that distance and the material forming its channel is porous. The loss due to both seepage and evaporation decreases as the canal is followed eastwardly after leaving this sidehill. The soil not only becomes more impervious to water, but the section of the canal is reduced as laterals decrease its discharge.

The total value of the crops grown under Canal No. 2 in 1899 was $126,500. This value was produced by the application of 16,432.35 acre-feet of water; hence the return from the use of each acre-foot as measured at the headgates of the canal was $7.69.

The return from an acre-foot of water varies with the crops grown. As an illustration of this, corn raised under the J lateral yielded 25 bushels per acre and sold for 30 cents per bushel, making a return of $7.50 per acre. To produce this 0.7 of an acre-foot of water was used on each acre of land, or the return for each acre-foot of water used was $10.71.

The return for the oats was $13.15 per acre; 1.55 acre-feet of water was used in its irrigation, making a return from each acre-foot of water used of $8.40. If a comparison were made with potatoes the difference would be much more striking. From this crop a return of $35 an acre was received. As but little more water was used in its cultivation than was used on the corn, the return for each acre-foot of water used was approximately $50.

MONTANA.

DUTY OF WATER IN THE GALLATIN VALLEY.

SAMUEL FORTIER, C. E.,
Professor of Irrigation Engineering, Montana Agricultural College.

INTRODUCTION.

In outlining a plan for the carrying on of investigations to determine the average quantity of water used on the irrigated farms of Montana, it was deemed best to begin the work in the Gallatin Valley.

This valley is justly termed the granary of the State, since it produces annually more than one-fourth of the cereals and contains within its boundaries more than one-eighth of the total irrigated area of Montana. The valley is 28 miles long and about 14 miles wide. It is traversed in a northwesterly direction by the Northern Pacific Railroad, and the elevations of the track at the towns of Bozeman, Manhattan, and Gallatin are 4,754 feet, 4,292 feet, and 4,032 feet, respectively.

To the south of the valley are to be found the sharp-pointed, snow-covered peaks of the Gallatin Mountains; on the east the steep incline lying between the East Gallatin River and the foot of the Bridger Range is thickly dotted with dry farms, which produce average yields of wheat without irrigation; a low range separates it from the Missouri Valley on the northwest and a plateau forms the divide between it and the Madison Valley on the west.

The area that may be brought under ditch in the Gallatin Valley is about 150,000 acres, and deducting 25 per cent for waste lands and tracts that are not susceptible of irrigation, there remains 112,500 acres of arable and irrigable land. A trifle less than one-half of this area is now irrigated.

The water supply for this entire tract of exceedingly fertile farming land may be obtained from the following sources in the quantities stated, which indicate approximately the average flow for June and July of each year, as determined by the engineers of the United States Geological Survey:

	Cubic feet per second.
West Gallatin River	1,000
Middle Creek	150
Cottonwood Creek	60
Other streams	250
Total	1,460

Since little irrigating water is used after August 1, each cubic foot per second is ample for 80 acres of land. One thousand four hundred and sixty cubic feet per second would thus irrigate 116,800 acres, or all of the good land in the valley.

EVAPORATION AND PRECIPITATION.

It was late in June before a decision was reached to ascertain the amount of evaporation during the crop-growing season, and there was then no time to procure a permanent steel tank. In the way of a substitute, a wooden box was made and lined with zinc. This box was made in the form of a cube, and contained when full a cubic yard of water. It was set in a grass plat at a considerable distance from any buildings, with its top edge but slightly raised above the surface of the ground, and filled to within 2 inches of the top with water. A woven-wire fence 12 by 12 feet and 3 feet high, supported by light pine posts and painted green, inclosed the tank.

The rate of evaporation was determined by taking measurements from a gage on the top of the tank to the water surface. As the water in the tank was evaporated, more was added. The following table shows the results of these measurements:

Evaporation at Bozeman, Mont., July 6 to September 30, 1899.

	Temperature in tank, 6 inches below surface.	Evaporation.
	° F.	*Inches.*
July 6 to 31, 1899	70	5.48
August, 1899	63	8.70
September, 1899	58	6.75

The following table shows the precipitation at the Montana Experiment Station for the calendar year 1899:

Precipitation on the Montana Experiment Station farm, Bozeman, for 1899. (Prof. R. S. Shaw, observer.)

	Inches.		Inches.
January	[1]0.78	August	0.80
February	[1]3.14	September	.56
March	1.93	October	1.12
April	.58	November	.61
May	1.82	December	.74
June	2.04		
July	.34	Total	14.46

[1] Approximate equivalent of water from snow fall.

EXPERIMENTS ON THE DUTY OF WATER IN 1899.

EXPERIMENT NO. 1.

In the southwest corner of the Montana Experiment Station farm here is a field of red clover containing nearly 31 acres. About half

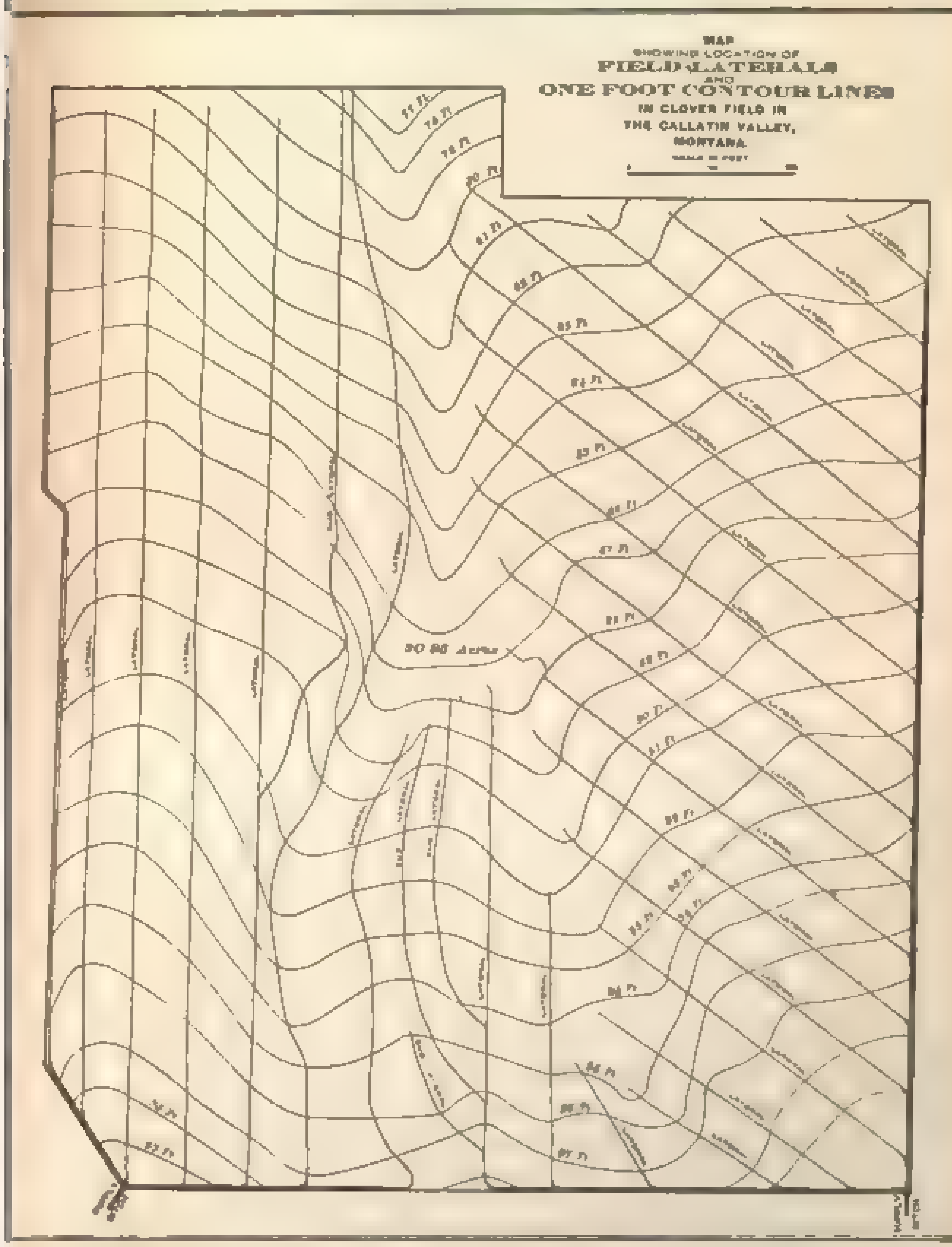


FIG. 15.—Map showing location of field laterals and contour lines in clover fields in Gallatin Valley, Montana.

of this field was seeded to clover in the spring of 1897 and the remainder was seeded to barley and clover in the spring of 1898. Two crops

were obtained during the past season, but owing to the late spring the second cutting was light. The total yield of cured hay was about 90 tons, or 3 tons per acre, and the prices per ton for clover hay delivered in Bozeman, one and one-half miles distant, have varied from $6 to $8.

Two supply ditches enter the field at the southwest and southeast corners, respectively. In June last a trapezoidal weir was placed in each supply ditch, and by means of automatic registering machines the depths of water over the weirs during the time of irrigation were recorded. The field slopes toward the north at the rate of nearly 80 feet to the mile, and also to a lesser degree toward a central ravine which traverses the field from south to north. With the exception of the area occupied by the ravine, which is formed of cobblestone overlaid with a shallow soil, the field is of average fertility. The best portions consist of 6 inches vegetable loam, 20 inches clay loam, 40 inches clay marl, and an unknown depth of gravel and cobblestone. The field laterals were made in 1897 and 1898 and were spaced from 60 to 90 feet apart, but averaged 80 feet. The accompanying diagram (fig. 15) shows the arrangement of field laterals.

In applying the water there was practically none wasted, and at each irrigation the main object sought was to wet the soil uniformly to a depth of 1 foot.

The following table contains the data pertaining to this experiment:

Duty of water on clover, as shown by experiment No. 1.

	First irrigation.	Second irrigation.	Total.
Date of irrigation	June 17-22	July 26–Aug. 2	....
Duration of irrigation ....hours..	104	115	....
Area irrigated ....acres..	27.44	27.44	27.44
Water used ....acre-feet..	13.35	14.57	27.92
Average depth of water applied ....feet..	.49	.53	1.02
Rainfall during growth ....do..	....	....	.44
Total depth of water received during growth ....do..	....	....	1.46
Number of irrigators	2	2	....
Average head of water used ....cubic feet per second..	1.55	1.53	....
Average distance between field laterals ....feet..	....	....	80

The table shows that a trifle less than 6 inches of water, if applied uniformly over the field, was used during the first watering, and a trifle more than this quantity was used during the second watering—that is to say, the depth of water used during the season was about 1 foot, there being 27.44 acres of land included in the experiment and 27.86 acre-feet of water applied. In addition to this, this crop received during its growth 5.28 inches of rainfall.

The average flow used by the irrigators was 1.54 cubic feet per second, or 61.6 Montana statutory inches, a somewhat smaller quantity than is usually preferred in this section of the State.

EXPERIMENT NO. 2.

The second experiment on the duty of water was conducted on a field of peas of the Mummy variety, 4.23 acres in extent, located near the southwest corner of the experiment station farm.

This field has been cropped continuously since 1893. It produced potatoes in 1894, barley in 1895, oats in 1896, peas in 1897, barley in 1898, and peas in 1899. The yield for the past season was 132.25 bushels on 4.23 acres, or 31.25 bushels per acre. The price at the experiment station granary has remained stationary since the harvest time at $1 per bushel.

The peas were sowed May 8, irrigated for the first time June 28, when the crop was about 9 inches high, irrigated a second time July 11 and 12, and harvested September 7.

The soil is somewhat richer than that described in experiment No. 1. There is more vegetable mold in the top layer and the depth to the porous stratum of gravel and cobblestone is fully 6 feet.

The field was irrigated in the usual manner with but a small percentage of waste. The following table shows the results of this experiment:

Duty of water on peas, as shown by experiment No. 2.

	First irrigation.	Second irrigation.	Total.
Date of irrigation	June 28	July 11-12	....
Duration of irrigation ... hours..	22	22	....
Area irrigated ... acres..	4.23	4.23	4.23
Water used ... acre-feet..	2.93	1.75	4.68
Average depth of water applied ... feet..	.69	.41	1.10
Rainfall, May 8 to September 7 ... do...	....	....	.41
Total depth of water received during growth ... do...	....	....	1.51
Number of irrigators	1	1	....
Average head of water used ... cubic feet per second..	1.61	.95	....
Average distance between field laterals ... feet..	....	....	60

EXPERIMENT NO. 3.

The quantity of water used on a grain field of 11.27 acres, located on the experiment farm west of the pea field, was also determined.

In this field there were 5.25 acres of barley and 6.02 acres of wheat; but since it was impossible to irrigate them at different times, the entire field was included in the experiment. The field slopes to the north at the rate of about 90 feet to the mile, and also to the east in a like degree. The steep inclines, coupled with the fact that the irrigators allowed a diminished flow to run all night without attention, caused considerable waste. The table shows that nearly 2 feet of water was run over this tract in the two irrigations, but it is safe to assert that if the water had been applied during the hours of daylight and carefully attended to a much smaller quantity would have sufficed.

The waste of water had no apparent effect on the yield, which was for the wheat slightly above the average, being 348½ bushels on 6.02 acres, or 57.89 bushels per acre. The barley averaged 45 bushels per acre.

The soil and subsoil of this grain field are similar to that described in experiment No. 2. It was seeded to oats in 1893, peas in 1894, and to barley in 1895. It was in clover for three years from 1896 to 1898, inclusive.

In regard to last year's crops, the barley was sowed May 9, irrigated June 25, when it was about 6 inches high, and again July 13, and harvested September 12 and 13.

The wheat was sowed May 8, irrigated at the same time as the barley, and harvested September 23.

The price of barley in Bozeman, Mont., during the past autumn has varied from 90 to 95 cents per bushel, and wheat has averaged about 75 cents per bushel.

The following table gives the result of experiment No. 3:

Duty of water on grain, as shown by experiment No. 3.

	First irrigation.	Second irrigation.	Total.
Date of irrigation	June 23-27	July 12-14	
Duration of irrigation ... hours	96	56	
Area irrigated ... acres	11.27	11.27	11.27
Water used ... acre-feet	14.34	7.96	22.30
Average depth of water applied ... feet	1.27	.71	1.98
Rainfall, May 8 to September 18 ... do			.42
Total depth of water received during growth ... do			2.40
Number of irrigators	2	2	
Average head of water used ... cubic feet per second	1.81	1.72	
Average distance between field laterals ... feet			90

EXPERIMENT NO. 4.

The quantity of water applied to a large field of barley belonging to the Hon. James E. Martin, and situated in the southeastern part of Gallatin Valley, was ascertained by means of a rating flume and recording register. A weir would have been preferred, but the requisite fall could not be obtained. The field was not watered until quite late, and then only one irrigation was given.

The greatest slope of the field was about 80 feet to the mile, or 3 inches to the rod, and the field laterals were parallel and ran diagonally through the field on a grade of about 1.5 inches to the rod. The distance between the laterals varied from 56 to 93 feet and averaged 69 feet. The soil consists of a clay loam, with a porous stratum of gravel wash beneath.

The barley field, after being summer fallowed in 1897, was seeded to barley and oats in the following year, and produced at the rate of 73 bushels per acre of barley and 50 bushels of oats.

The following table shows the quantity of water used on this field:

Duty of water on barley, as shown by experiment No. 4.

Date of irrigation	July 5–13
Duration of irrigation ... hours..	196
Area irrigated ... acres..	66.39
Water used ... acre-feet..	65.37
Average depth of water applied ... feet..	.98
Rainfall during period of growth ... do...	.41
Total depth of water received during growth ... do...	1.39
Number of irrigators	2
Average head of water used ... cubic feet per second..	4.04
Average distance between laterals ... feet..	69

EXPERIMENT NO. 5.

The quantity of water used on a field of oats 23.41 acres in extent, situated below the barley field described in experiment No. 4, and likewise owned by Mr. Martin, was determined. In this case considerable water was wasted. The topography of the field was irregular, and it was difficult to irrigate. In addition to this a slough extended along the west and north sides into which a large percentage of the water applied found its way. Under favorable conditions and having as even a surface this field should have required less water in proportion to its area than that used in experiment No. 4.

The yield was 1,200 bushels of oats, or 51 bushels per acre.

The following table gives the data of this experiment:

Duty of water on oats, as shown by experiment No. 5.

Date of irrigation	July 13–18
Duration of irrigation ... hours..	122
Area irrigated ... acres..	23.41
Water used ... acre-feet..	35.73
Average depth of water applied ... feet..	1.53
Rainfall during period of growth ... do...	.38
Total depth of water received during growth ... do...	1.91
Number of irrigators	2
Average head of water used ... cubic feet per second..	3.54
Average distance between field laterals ... feet..	85

EXPERIMENT NO. 6.

Experiment No. 6 was made on a field of oats situated on the south side of the experiment station farm containing 7.26 acres. This field has been cropped continuously since the establishment of the experiment farm. Barley was raised on this field in 1894, potatoes and peas in 1895, barley in 1896, peas and grain in small plats in 1897, and barley and other grains in small plats in 1898.

The oat crop of the past summer was seeded May 19, irrigated July 6 and 7, irrigated again July 22 to 24, and reaped September 18.

The average yield of all the oats raised last season on the experiment farm was 72.75 bushels per acre, and the price has increased from 95 cents at threshing time to $1.15 per hundred pounds in February.

Duty of water on oats, as shown by experiment No. 6.

	First irrigation.	Second irrigation.	Total.
Date of irrigation	July 6-7	July 22-24	
Duration of irrigation ... hours	24	48.25	
Area irrigated ... acres	7.26	7.26	7.26
Water used ... acre-feet	2.63	7.11	9.74
Average depth of water applied ... feet	.36	.98	1.34
Rainfall from May 19 to September 18 ... do			.36
Total depth of water received during growth ... do			1.70
Number of irrigators	1	1	
Average head of water used ... cubic feet per second	1.33	1.78	
Average distance between field laterals ... feet			75

EXPERIMENT NO. 7.

This experiment was tried on a small field of oats on the station farm. It was seeded May 23 and cut September 18, thus taking 119 days to mature. The yield was at the rate of 72.75 bushels per acre.

In irrigating it was found impracticable to prevent part of the water from flowing on adjacent fields. Hence the flow over the weir did not accurately represent the quantity actually applied to the land at the first irrigation. At the second watering more accurate results were obtained. The following table shows the quantity of water passing over the weir:

Duty of water on oats, as shown by experiment No. 7.

	First irrigation.	Second irrigation.	Total.
Date of irrigation	July 7-8	July 25	
Duration of irrigation ... hours	23.25	10	
Area irrigated ... acres	2.48	2.48	2.48
Water used ... acre-feet	3.70	1.66	5.36
Average depth of water applied ... feet	1.49	.67	2.16
Rainfall from May 23 to September 18 ... do			.36
Total depth of water received during growth ... do			2.52
Number of irrigators	1	1	
Average head of water used ... cubic feet per second	1.92	2.01	

EXPERIMENT NO. 8.

This test was made on a field of oats containing a trifle over 25 acres, owned by Mr. J. L. Patterson, county commissioner of Gallatin County.

The water was measured over two trapezoidal weirs placed side by side at the same elevation, the depth of water over the crest of each being recorded by one Gurley register.

This field received a thorough watering, and if part was wasted it must have been due to percolation through the soil, which is shallow in places, and not to run off from the field. The results of this experiment are shown in the following table:

Duty of water on oats, as shown by experiment No. 8.

Date of irrigation	July 20–26
Duration of irrigation ....hours..	123.5
Area irrigated ....acres..	25.09
Water used ....acre-feet..	32.00
Average depth of water applied ....feet..	1.28
Rainfall during period of growth ....do...	.44
Total depth of water received during growth...do...	1.72
Number of irrigators	1
Average head of water used ....cubic feet per second..	3.13
Average distance between field laterals ....feet..	85

CONCLUSIONS.

(1) The average of the eight experiments shows approximately 1.2 acre-feet of water used for each acre irrigated.

(2) Irrigating with insufficient help is wasteful of water.

(3) Much more water is required when the irrigating streams are allowed to run all night without attention.

(4) Irrigating late in the season retards the ripening of grain, and on account of the prevalence of early frosts it is not advisable to apply water on grain lands after August 1.

(5) Little water is used before June 15 in this locality. The so-called irrigation period is therefore only 45 days.

DUTY OF WATER FLOWING IN MIDDLE CREEK CANAL.

In ascertaining the duty of water for a field of known area, when the flow is measured as it enters the highest corner of the field, all losses due to conveyance are excluded. In the eight experiments previously described the loss of water due to seepage and percolation from the bottom and sides of the main canal and supply ditches and from evaporation was not considered. The quantity of water which flowed onto the field selected for an experiment, together with the incidental losses due to the character of the soil and the lack of skill or negligence on the part of the irrigator, was taken to compute the duty in that particular case.

We have now to consider the duty of water under entirely different conditions. It must now be debited with all the losses and waste which occur from the time the water leaves its natural source until it forms part of the mechanical constituents of the irrigated farms. A momentary reflection will convince the observer that a much larger

canal follows a steep sidehill for that distance and the material forming its channel is porous. The loss due to both seepage and evaporation decreases as the canal is followed eastwardly after leaving the sidehill. The soil not only becomes more impervious to water, but the section of the canal is reduced as laterals decrease its discharge.

The total value of the crops grown under Canal No. 2 in 1899 was \$126,500. This value was produced by the application of 16,432.3 acre-feet of water; hence the return from the use of each acre-foot as measured at the headgates of the canal was \$7.69.

The return from an acre-foot of water varies with the crops grown. As an illustration of this, corn raised under the J lateral yielded 25 bushels per acre and sold for 30 cents per bushel, making a return of \$7.50 per acre. To produce this 0.7 of an acre-foot of water was used on each acre of land, or the return for each acre-foot of water used was \$10.71.

The return for the oats was \$13.15 per acre; 1.55 acre-feet of water was used in its irrigation, making a return from each acre-foot of water used of \$8.40. If a comparison were made with potatoes the difference would be much more striking. From this crop a return of \$35 an acre was received. As but little more water was used in its cultivation than was used on the corn, the return for each acre-foot of water used was approximately \$50.

MONTANA.

DUTY OF WATER IN THE GALLATIN VALLEY.

SAMUEL FORTIER, C. E.,
Professor of Irrigation Engineering, Montana Agricultural College.

INTRODUCTION.

In outlining a plan for the carrying on of investigations to determine the average quantity of water used on the irrigated farms of Montana, it was deemed best to begin the work in the Gallatin Valley.

This valley is justly termed the granary of the State, since it produces annually more than one-fourth of the cereals and contains within its boundaries more than one-eighth of the total irrigated area of Montana. The valley is 28 miles long and about 14 miles wide. It is traversed in a northwesterly direction by the Northern Pacific Railroad, and the elevations of the track at the towns of Bozeman, Manhattan, and Gallatin are 4,754 feet, 4,292 feet, and 4,032 feet, respectively.

To the south of the valley are to be found the sharp-pointed, snow-covered peaks of the Gallatin Mountains; on the east the steep incline lying between the East Gallatin River and the foot of the Bridger Range is thickly dotted with dry farms, which produce average yields of wheat without irrigation; a low range separates it from the Missouri Valley on the northwest and a plateau forms the divide between it and the Madison Valley on the west.

The area that may be brought under ditch in the Gallatin Valley is about 150,000 acres, and deducting 25 per cent for waste lands and tracts that are not susceptible of irrigation, there remains 112,500 acres of arable and irrigable land. A trifle less than one-half of this area is now irrigated.

The water supply for this entire tract of exceedingly fertile farming land may be obtained from the following sources in the quantities stated, which indicate approximately the average flow for June and July of each year, as determined by the engineers of the United States Geological Survey:

	Cubic feet per second.
West Gallatin River	1,000
Middle Creek	150
Cottonwood Creek	60
Other streams	250
Total	1,460

borne by the rapidly moving water in Middle Creek would have been deposited on the bottom of the canal and rendered it in time nearly impervious. Under existing conditions the deposition of sediment is impossible owing to the high velocity, and practically the same conditions have existed during the life of the canal, a period of twenty-eight years.

Soon after the canal was excavated the finer particles of soil, sand, and gravel within the water area of the channel were carried away, leaving a bed of cleanly washed cobblestones. This is true of the upper portion of the canal, but the formation changes in the second mile to a clay soil and subsoil with gravel and cobblestone beneath. In the lower 2 miles the seepage is small, except at gravel bars and

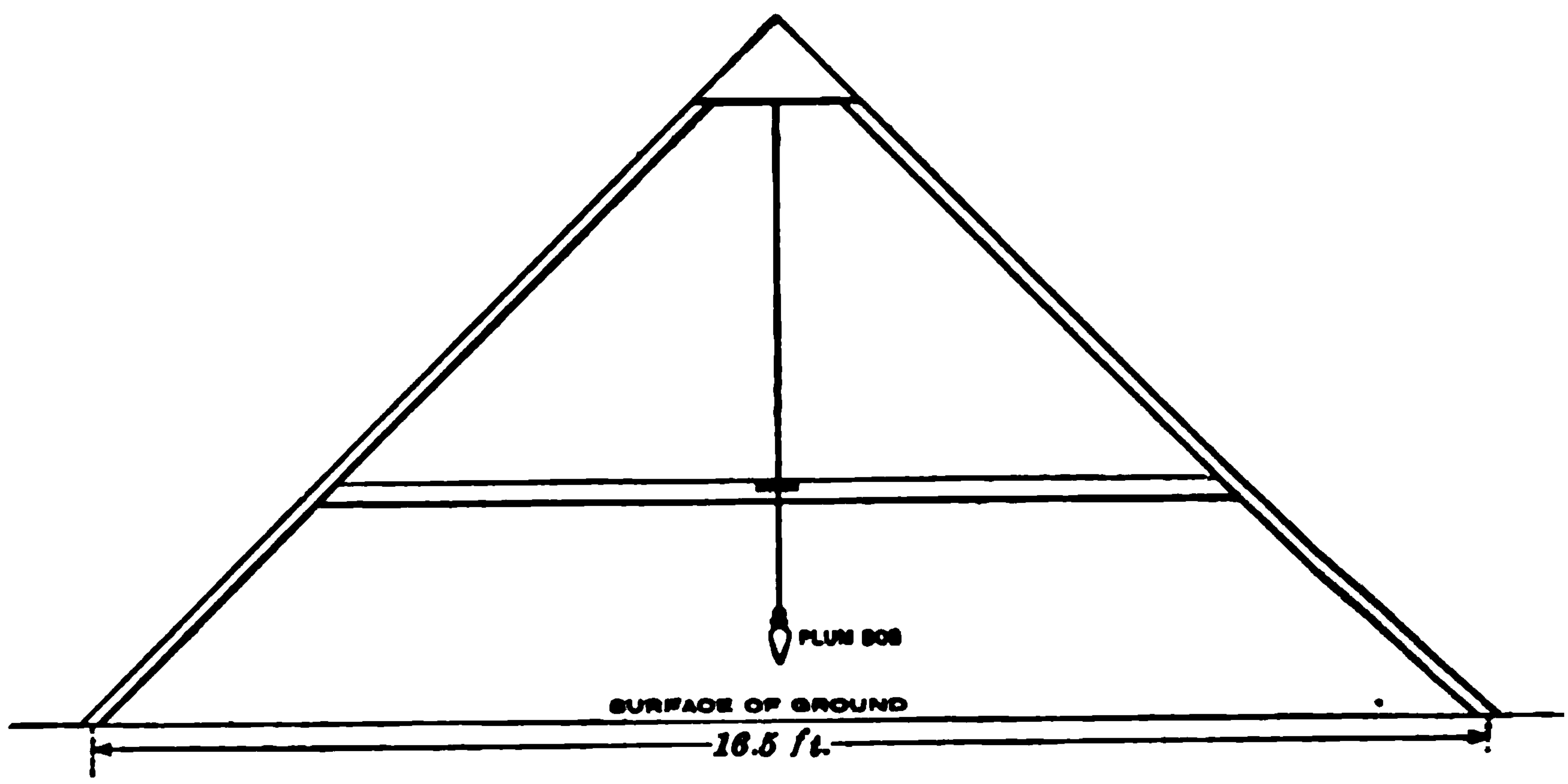


FIG. 16.—The pioneer ditch level.

where the high velocity has eroded the clay subsoil, thus exposing the rocky and porous substratum.

On July 10, 1899, when the flow of the canal was nearly at its highest point, the writer, aided by his assistant, Mr. Stanley Koch, determined by means of a complete series of ditch and canal measurements the loss due to seepage throughout the length of the main canal, a distance of 4 miles. The main canal was measured below the headgate at the rating flume on the morning of July 10, and during the day a complete series of measurements was made of all the laterals and branches diverting water therefrom. The results are summarized in the accompanying table.

EXPERIMENTS ON THE DUTY OF WATER IN 1899.

EXPERIMENT NO. 1.

In the southwest corner of the Montana Experiment Station farm there is a field of red clover containing nearly 31 acres. About half

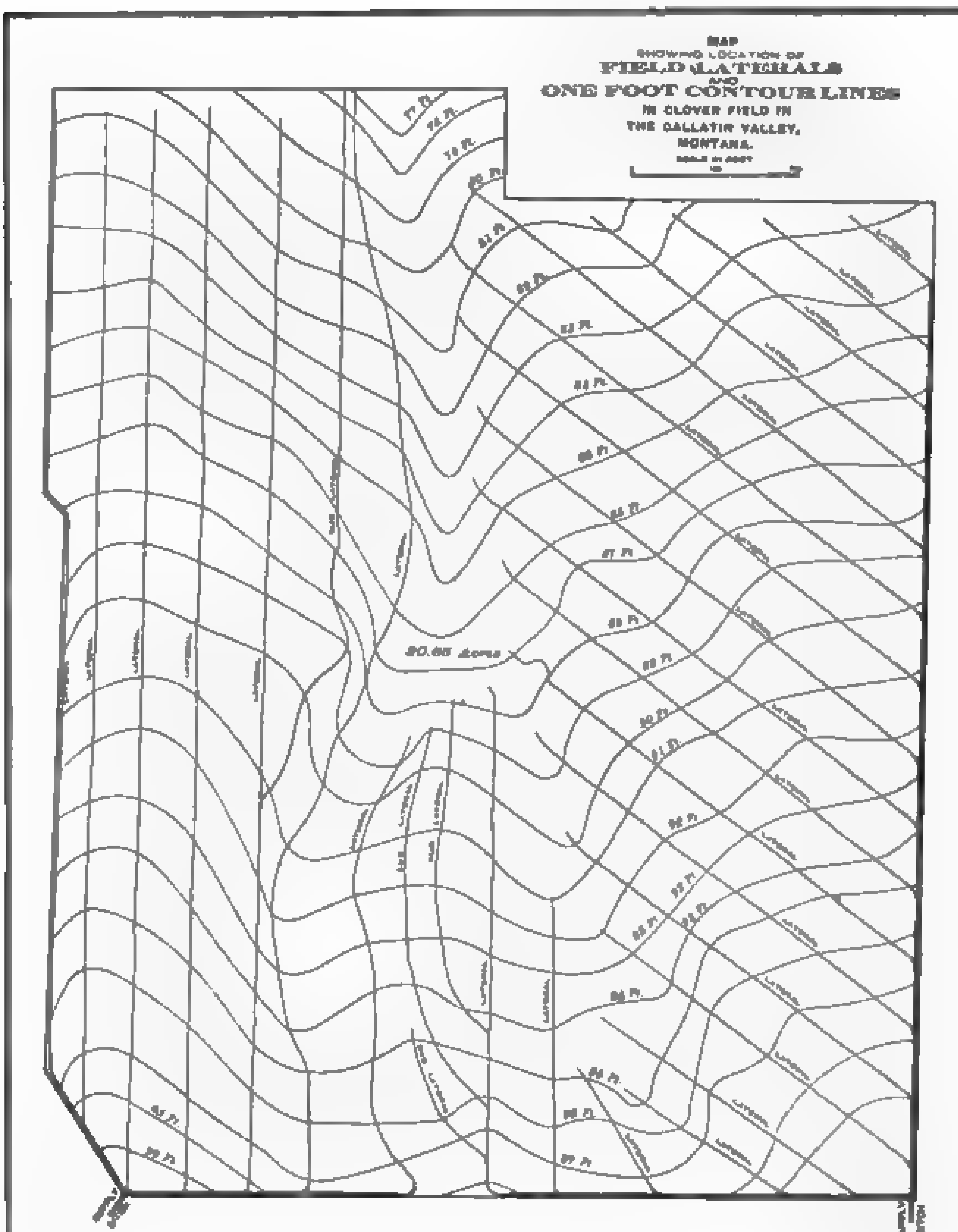


FIG. 15.—Map showing location of field laterals and contour lines in clover fields in Gallatin Valley, Montana.

of this field was seeded to clover in the spring of 1897 and the remainder was seeded to barley and clover in the spring of 1898. Two crops

same quantity of water being wasted may be roughly estimated at $20 more, or $50 in all. Now as there are 20 cubic feet per second wasted, the total loss is $1,000 per annum, or, considering money worth 8 per cent, the expenditure of $12,500 would be justifiable in preventing the loss of 20 cubic feet per second of water.

CONDITIONS AFFECTING THE DUTY OF WATER IN MONTANA.

METHOD OF DISTRIBUTION.

Throughout Montana the waters of a creek or canal are usually divided among the respective claimants or shareholders, in continuous streams, in proportion to the recognized rights of each owner. Were it not for the large farms of this State a division by constant flow would be impracticable. It is wasteful of water as it is, and if the distribution by time as practiced in Utah and southern California were better understood by the Montana irrigators it would be speedily adopted in many sections.

A Utah farmer who owns but 20 acres can not well irrigate his farm by means of a continuous stream. Only 10 miner's inches flowing through his division box may require as many days to flow over 20 acres. Whereas if he can get 50 inches for two days he will not only water his farm more uniformly but save the labor of eight days.

By the census of 1890 the average size of the Montana irrigated farm was 95 acres, or nearly four times as large as that of Utah. If the water supply be abundant, little objection can be raised to the use of a continuous stream for 160 acres, because the allotment for this area would be as much water as one man could handle. In seasons of scarcity, and for farms that are 80 acres or less, a constant flow is not economical of either water or labor. Under such circumstances the division should be made for stated periods, or by the time method, by which each irrigator would have a large flow, say, twice a week, instead of a small flow daily. The day is not far distant when the farms that are now 160, 240, and 320 acres in extent will be subdivided into 80-acre farms, and when that time comes the division of water by time will be the rule and not the exception.

DIVERSIFIED FARMING.

Water can not be economically used on farms that produce only grain crops. This is true of both large and small holdings. While irrigation lasts the volumes applied are large and the time limited. Ten days may suffice to water a grain crop. It is thus evident there is a great loss to him who can make use of his share of a creek or canal during only one-fourth or perhaps one-sixth of the irrigation period. So long as Montana irrigators continue to seed the greater part of their farms to barley, oats, and wheat, as is now done in the Gallatin

Valley, they can not hope to make the most of their available water supply. All the cereals named require to be irrigated at nearly the same time. In many cases seven days' delay after the right time has come will materially reduce the yield. A shareholder can not, therefore, without incurring damage, allow others to use all the water during the first two weeks of July for the privilege of having his share during the third week. The extent of land seeded to grains under any particular stream or canal must not exceed that which can be watered simultaneously.

The writer has no desire to attempt to instruct the farmers of this State in the kinds of crops to raise. That is their business. If, however, the same profits could be made from diversified farming, the area now watered in many parts might be increased by one-half.

On an 80-acre farm as now cultivated in the Gallatin Valley one may find 40 acres in grain, 10 acres in meadow, 20 acres summer fallowed, and the remainder in pasture, or occupied by buildings. In this case only 50 out of 70 arable acres are productive, and the bulk of the water required is used from July 4 to 15. Now, in more diversified farming the acreage and kinds of crops might be as follows: 22 in grain, 15 in red clover or alsike, 10 in alfalfa, 10 in timothy, 8 in potatoes, 3 in mangel-wurzels, and 2 acres in garden, or 70 acres in all.

In the latter case the value of the yield is easily double that of the former, and by exercising good judgment an equal allotment of water if used for a longer period would suffice. On the farm producing chiefly grain the irrigation period may be only twenty days, whereas on the diversified farm water may be used over a period of fifty days.

LOSS DUE TO SEEPAGE IN CONVEYING WATER.

We have just seen that the loss due to seepage in the upper four miles of Middle Creek Canal is nearly 22 per cent of the total flow. It is reasonable to conclude that the corresponding loss in the main branches and canal laterals is 15 per cent more, making 35 per cent in all. It is thus seen that the duty of water for a particular field or crop is not identical with that for a canal, since the amount of water applied depends on the place of measurement.

In regard to the percentage of loss, Middle Creek Canal and its branches are not different from hundreds of canals now being operated in this State. For every 100 cubic feet per second diverted, it is quite probable that not more than 60 cubic feet per second ever reach the fields of the irrigators. To corroborate this statement, the percentages of loss in the upper portions of a few canals in the State of Utah, as determined by the writer in 1893, are herewith given. In the case of the first named, the distance included the whole length of the main canal. Ten years prior to the time the test was made the loss was 50 in the main canal, but owing to the deposition of sediment the decreased more than one-half in that period.

Losses by seepage from canals in Utah.

Name of canal.	Discharge.	Loss.	Distance.
	Cubic feet per second.	*Per cent.*	*Miles.*
Utah and Salt Lake Canal	185.0	22	28
Davis and Weber Counties Canal	105.5	26	10
Logan, Hyde Park and Smithfield Canal	48.0	44	1.5
Bear River Canal	71.2	6.7	5
Ogden Bench Canal	11.5	18	1.5

GRADING THE SURFACE OF THE FIELDS.

To irrigate land that has an uneven surface and an irregular grade results in a needless waste of water, additional labor, small crops, and eventually a deteriorated soil. In irrigating by flooding between small field laterals, a method commonly practiced in Rocky Mountain States, the surface of the land between any two laterals requires to be fairly even and of uniform grade; otherwise the water as it spreads from the higher lateral will run into the low places only and leave the high places untouched. The injurious effects of applying too much water to some portions of the field and none to other portions are soon apparent. To use the irrigator's expression, the crop of the high ground becomes "burnt," that on the low ground "water-logged."

In trying to prevent injury to the crop on fields that are uneven, the irrigator frequently performs double and treble the labor that would be required under more favorable conditions. With the utmost care, it is seldom possible to obtain a good crop. The yield on the dry places is not only lessened, but its time of ripening is hastened. In autumn it is not uncommon to see fields that look like a chessboard, yellow and green in alternate patches. The first to mature shells out in reaping, and the last, in the high altitudes of this State, is apt to be affected by frosts. In order to have a crop of uniform quality throughout, the irrigating water must be evenly applied over the entire surface, but this can not be done unless the surface is graded. Western farmers are beginning to realize that it pays to level the surface. This knowledge has been acquired by costly experience. It is to be hoped that the lesson thus taught will not soon be forgotten.

Until recent years, the implements used to grade the surface were either mere makeshifts, or else were designed for work of an entirely different character. The V-shaped leveler made of planks or timbers, and loaded with rocks in the center, serves the double purpose of crushing the sods and leveling the surface. It has, however, but one good feature to recommend it, and that is its low cost.

The ordinary scraper or railroad slip has also been extensively used. If the object to be attained were the removal of earth from one place to another less than 150 feet distant, the scraper would be effective. As a rule it is better adapted to digging holes than it is to making rough places smooth. These objections hold true for the ordinary

two-wheeled scraper, as well as the Fresno scraper, although the latter, having a longer blade, is to be preferred. Many irrigators have also made use of the various kinds of road graders, but the larger implements are too unwieldy. The two-wheeled four-horse road grader is the most serviceable for grading land.

On the Montana Experiment Station farm considerable land leveling was formerly done with the Shuart grader. This device consists of a steel blade 5 feet 6 inches long and 15 inches deep, supported on a frame, and is raised and lowered by a lever. The frame, which is about 6 feet square, rests in front on a pair of short steel-shod runners and in the rear on two 20-inch iron wheels. Very effective work can be done with this small implement in the way of removing earth from the high to the low places. It has, however, two serious defects. The cutting blade is short, and the grader when in operation has often a rocking motion in the direction in which the team is moving, which leaves the surface undulated rather than level.

THOROUGH CULTIVATION.

Thorough cultivation is considered necessary in good farming in humid countries. The needs of the cultivated plants require a finely pulverized soil. To a greater extent is this true in an arid region like Western America. Here surface cultivation serves a double purpose. It not only renders the plant food of the soil available, but, by preventing evaporation, retains the moisture in the soil. To the Western irrigator a soil mulch two or three inches deep over his cultivated fields is as essential as asbestos covering on the steam pipes of the mechanical engineer. It is a grave mistake to conclude that the artificial application of water to soil can take the place of cultivation. In applying large quantities of water by the flooding system in a careless manner, one is apt to make a paste of the top soil. When this is done, in less than sixty hours the moisture in this top layer may be evaporated, leaving it hard and baked. Under such conditions it is astonishing how rapidly the soil moisture is converted into vapor. If this process is long continued there will be found little moisture within a foot of the surface, the crops begin to suffer for lack of moisture, and the unskilled irrigator, ignorant of the real cause, applies more water in the same careless manner. Now, in many cases this second watering following so closely after the first might have been wholly unnecessary if the proper means had been used to prevent the baking of the top layer of soil and the consequent excessive evaporation.

METHODS ADOPTED IN IRRIGATING.

The duty of water depends to a large extent on the skill and appli-

Attention has already been directed to the need

to lessen the evaporation, as well as a

ver which water can readily flow. We

have now to consider the equally important features of the location of the furrows, or field laterals, and the best manner of conducting the water flowing therein to the roots of the growing crops.

Much depends on the proper location of farm laterals. The intelligent farmer, who cultivates and irrigates for years the same 80 or 160 acre tract, learns by experience what he terms the "lay of the land." He has learned the right direction for his laterals, or ditches, their proper distances apart, and how to locate them so as to cover the high places with water. The beginner learns by the mistakes he makes. A common mistake is to run the laterals in the direction of the greatest slope and to have them too far apart. A better way, as a general rule, is to locate the laterals as near as practicable, consistent with a grade of from one-half to 1 inch to the rod, at right angles to the steepest slope, in which case the water will flow and spread without trouble from each lateral.

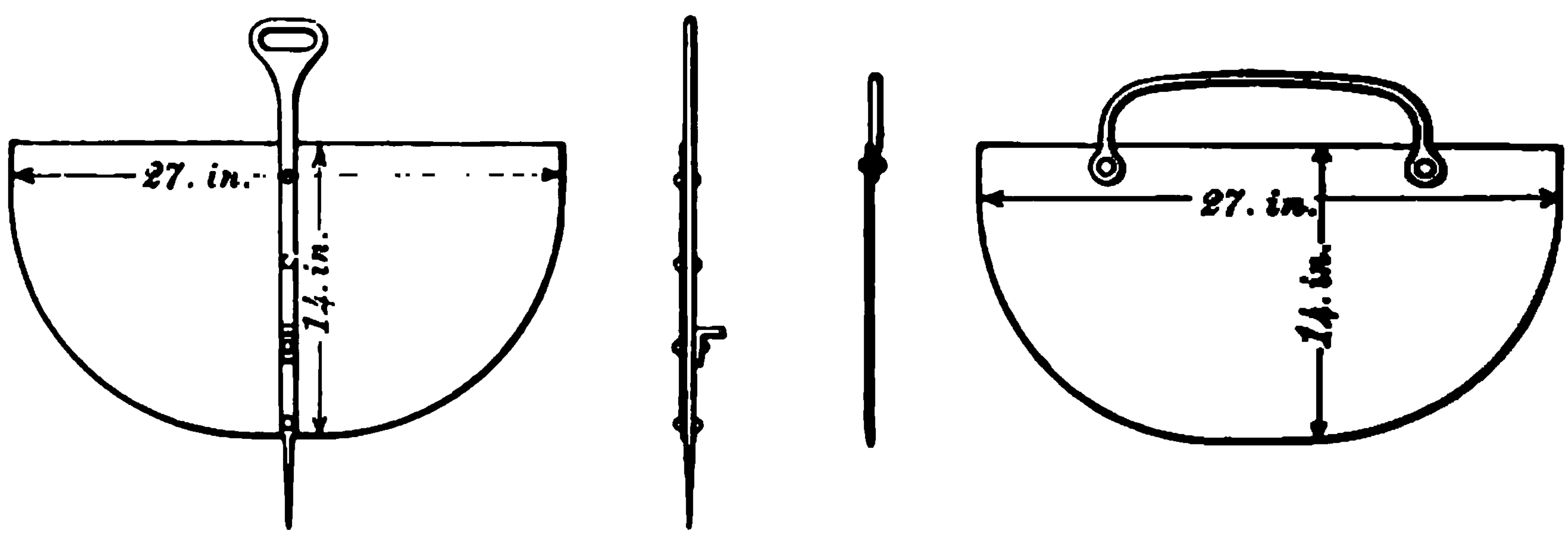


FIG. 17.—Two forms of the steel dam.

The inexperienced farmer also frequently attempts to force the water over too great distances. His plow furrows, or laterals, instead of being from 50 to 100 feet apart, may be three times those distances, and in irrigating with a small flow it is difficult to cover with water all the intervening space.

In this locality, when the laterals have been made in the grain fields with a ditch plow, it is customary to run over them with an implement called a "dammer" (Pl. XLIV, fig. 1) drawn by one horse. It consists of a large shovel attached to handles resembling those of a plow. As the horse travels, the shovel collects the loose dirt in the bottom of the double furrow and when the driver raises the handles it is deposited in a heap to form a dam. These dams are spaced from 40 to 75 feet apart, depending somewhat on the slope of the lateral. The object of these earth dams in laterals is to hold back the water and permit it to overflow the lower bank. This being accomplished, the dam is broken and the unused portion of the water, together with the flow of the irrigation stream, is temporarily checked by the next lower earth dam. In the clover and timothy fields of the Gallatin Valley little piles of manure are placed in the laterals for the same

FIG. 1.—USING THE DITCH PLOW IN MONTANA.

FIG. 2.—FURROW IRRIGATION OF SUGAR BEETS IN MONTANA.

This field received a thorough watering, and if part was wasted it must have been due to percolation through the soil, which is shallow in places, and not to run off from the field. The results of this experiment are shown in the following table:

Duty of water on oats, as shown by experiment No. 8.

Date of irrigation	July 20–26
Duration of irrigation ... hours	123.5
Area irrigated ... acres	25.09
Water used ... acre-feet	32.00
Average depth of water applied ... feet	1.28
Rainfall during period of growth ... do	.44
Total depth of water received during growth ... do	1.72
Number of irrigators	1
Average head of water used ... cubic feet per second	3.13
Average distance between field laterals ... feet	85

CONCLUSIONS.

(1) The average of the eight experiments shows approximately 1.2 acre-feet of water used for each acre irrigated.

(2) Irrigating with insufficient help is wasteful of water.

(3) Much more water is required when the irrigating streams are allowed to run all night without attention.

(4) Irrigating late in the season retards the ripening of grain, and on account of the prevalence of early frosts it is not advisable to apply water on grain lands after August 1.

(5) Little water is used before June 15 in this locality. The so-called irrigation period is therefore only 45 days.

DUTY OF WATER FLOWING IN MIDDLE CREEK CANAL.

In ascertaining the duty of water for a field of known area, when the flow is measured as it enters the highest corner of the field, all losses due to conveyance are excluded. In the eight experiments previously described the loss of water due to seepage and percolation from the bottom and sides of the main canal and supply ditches and from evaporation was not considered. The quantity of water which flowed onto the field selected for an experiment, together with the incidental losses due to the character of the soil and the lack of skill or negligence on the part of the irrigator, was taken to compute the duty in that particular case.

We have now to consider the duty of water under entirely different conditions. It must now be debited with all the losses and waste which occur from the time the water leaves its natural source until it forms part of the mechanical constituents of the irrigated farms. A momentary reflection will convince the observer that a much larger

The Gallatin Valley farms are large. From statistics collected by the Montana Experiment Station in 1893 the average size of farms in Gallatin County was 196 acres. It is not uncommon, therefore, for one farmer to cultivate and irrigate 200 acres of land. Such being the case, it is impossible to give that close attention to details in properly cultivating and irrigating the soil that one would look for on a well-tilled farm of 20 acres.

The low average yield on a big farm is chiefly due to careless and overhasty irrigation. There is often a difficulty and sometimes a disinclination on the part of the proprietor to engage a sufficient number of irrigators. Experienced irrigators are also a necessity. Even with skilled help results are not always satisfactory.

The prevalent custom throughout the Gallatin Valley during the time of irrigating is to control and guide the course of the irrigating stream during daylight and permit it to run "wild," or without attention, during the night. This slovenly custom is a direct result of large farms and insufficient help and has been practiced so long that it is now difficult to abandon it.

Many a farmer has the yield reduced one-third through carelessness, or inattention, in not applying water at the right time, or in the proper manner. In this way the average yield is not only decreased, but a large percentage of the land is being rendered unproductive by the presence of too much water. It is unreasonable to suppose that each farmer may allow 80 miner's inches of water to flow at random over his field every night, while water is being used, and not damage either his own or his neighbor's land.

On good soil, where the defects named are remedied, the returns are unusually large. Last fall a Mr. Arnold obtained on an average 84 bushels of barley for each acre seeded. Another year a Mr. Gouch's large field of oats averaged over 100 bushels per acre. Sixty-five bushels of wheat to the acre are not uncommon. And so numerous other examples might be cited of large yields, but as there is seldom any opportunity given to investigators to verify the reports, they are of comparatively little value.

Herewith is presented, however, reliable statistics obtained through the courtesy of Prof. R. S. Shaw, agriculturist of the Montana Experiment Station, of crops raised under his direction and supervision during the past season. It is questionable if Professor Shaw's results can be duplicated east of the Missouri River. The straw and grain were accurately weighed, and the areas were obtained not by measuring the actual surface of each plat, but by ascertaining its area as a part of a large field.

The dates of applying water are given in each case, as well as those of seedtime and harvest time, an important consideration in an irrigated region located so far north:

Barleys grown at the Montana Experiment Station, 1899.

No.	Name of variety	Period of growth.			Date irrigated		Yield per acre.	
		Seeded	Harvested.	Days to mature.	First irrigation	Second irrigation	Straw.	Grain.
							Pounds.	*Bushels.*
1	Goldenthorpe	May 19	Sept. 15	119	July 3	July 25	3,030	68.1
2	Black Hulless	do	Aug. 28	101	do	do	2,580	62.5
3	Highland Scotch	do	Sept. 8	112	do	do	3,930	60.6
4	Guy Male	do	Aug. 28	101	do	do	2,610	60.6
5	Manshury	do	do	101	do	do	4,500	58.7
6	New Zealand	do	Sept. 15	119	do	do	3,660	58.7
7	Manshury	do	Sept. 8	112	do	do	3,150	56.8
8	Italian	do	Sept. 2	106	do	do	3,360	56.2
9	Smooth Hulless	do	Aug. 28	101	do	do	3,090	55.6
10	New White Hulless	do	Sept. 1	106	do	do	2,940	55.0
11	Winnipeg	do	Aug. 28	101	do	do	2,940	53.7
12	Imp. Cheyenne	do	Sept. 6	110	do	do	4,110	53.1
13	King 9-10	do	Aug. 28	101	do	do	3,270	57.8
14	Manhattan	do	Sept. 4	108	do	do	4,770	50.6
15	Chevalier	do	Sept. 1	105	do	do	3,420	48.7

NOTE.—First fifteen out of a list of twenty-five

Oats grown at the Montana Experiment Station, 1899.

No.	Name of variety.	Period of growth.			Date irrigated.		Yield per acre.	
		Seeded.	Harvested.	Days to mature.	First irrigation.	Second irrigation.	Straw.	Grain.
							Pounds.	*Bushels.*
1	Russian 2786	May 16	Sept. 15	120	July 3	July 25	4,740	107.6
2	Canadian White	May 17	Sept. 17	123	do	do	5,190	92.6
3	White Swede	do	do	123	do	do	3,300	91.7
4	American Beauty	May 18	Sept. 15	120	do	do	3,790	86.4
5	Archangel	May 17	do	121	do	do	4,050	85.5
6	Great Northern	do	do	121	do	do	4,470	85.5
7	Nameless Beauty	do	Sept. 14	120	do	do	3,360	84.7
8	Giant Yellow	do	Sept. 18	124	do	do	4,030	84.7
9	White Danish	May 18	Sept. 15	120	do	do	3,450	83.6
10	Siberian (15)	May 17	do	121	do	do	3,480	82.9
11	Black Tartarian	do	Sept. 17	123	do	do	3,780	82.9
12	Victoria	May 16	Sept. 10	117	do	do	3,660	79.4
13	Poland White	do	Sept. 9	123	do	do	3,000	79.4
14	Giant Yellow	May 18	Sept. 15	120	do	do	3,570	78.5
15	Nebraska	May 16	do	122	do	do		77.6

NOTE.—First fifteen out of a list of forty-eight.

Spring wheats grown at the Montana Experiment Station, 1899.

No.	Name of variety.	Period of growth.			Date irrigated.		Yield per acre.	
		Seeded.	Harvested.	Days to mature.	First irrigation.	Second irrigation.	Straw.	Grain.
							Pounds.	*Bushels.*
1	Onyx	May 12	Sept. 22	133	July 5	July 26	4,650	74.5
2	Opal	do	do	133	do	do	4,440	73.0
3	Amethyst	do	do	134	do	do	6,870	67.5
4	Bordeau N M 472	do	do	133	do	do	7,680	64.0
5	Black-Bearded Centennial	do	do	133	do	do	5,040	64.0
6	Gneiss	do	do	133	do	do	4,710	63.5
7	Nose B	do	do	133	do	do	5,400	59.0
8	Gypsum	do	do	133	do	do	5,490	58.0
9	Chili	do	do	133	do	do	4,200	56.0
10	Ladoga	May 13	Sept. 5	116	do	do	3,570	53.5
11	Glyndous 676	May 12	Sept. 22	133	do	do	4,980	49.0
12	Glyndous 661	do	do	133	do	do	5,460	49.0
13	Imp. Russian R 6, P 1	May 13	Sept. 15	126	do	do	5,400	49.0
14	Glyndous 692	May 12	Sept. 22	133	do	do	5,100	48.0
15	Hungarian Mountain	May 13	Sept. 16	127	do	do	3,180	48.0

NOTE.—First fifteen out of a list of sixty-seven.

Results of potato experiments, Montana Experiment Station, 1899.

No.	Name of variety	Period of growth.		Date irrigated.		Yield per acre.	
		Planted	Harvested.	First irrigation.	Second irrigation.	Total.	Marketable.
						Bushels.	*Per cent.*
1	Montana Beauty	May 25	Oct. 6 and 7	July 5	July 22	999.3	80.4
2	Rural New Yorker No. 2	do	do	do	do	998.4	80.8
3	Beauty of Hebron	do	do	do	do	961.8	70.2
4	Winters White	do	do	do	do	860.3	79.7
5	Rural Blush	do	do	do	do	821.6	[illegible]
6	White Elephant	do	do	do	do	821.6	62.6
7	Irish Daisy	do	do	do	do	782.6	78.6
8	White Star	do	do	do	do	773.3	69.7
9	Charles Downing	do	do	do	do	768.5	74.8
10	New Queen	do	do	do	do	756.8	77.0
11	Unknown	do	do	do	do	739.5	90.6
12	Jennie	do	do	do	do	729.8	70.8
13	Lee Favorite	do	do	do	do	729.8	[illegible]
14	Early Telephone	do	do	do	do	705.6	77.6
15	Crown Jewel	do	do	do	do	696.0	65.1

NOTE.—First fifteen out of a list of sixty-four.

UTAH.

DUTY OF WATER ON BIG COTTONWOOD CREEK.

By Special Agent R. C. Gemmell,
State Engineer of Utah.

Big Cottonwood Creek is a beautiful mountain stream, rising in the heart of the Wasatch Mountains, about 20 miles southeast of Salt Lake City, and having a drainage area of about 48.5 square miles. At its head are a number of small picturesque lakes, situated at an elevation of from 8,500 to 10,000 feet above sea level. Some of these lakes have been segregated by the United States for reservoir sites, viz, Silver Lake, Twin Lakes, and Marys Lake. From its source this stream flows about 12 miles in a general westerly direction, through a rugged, magnificent canyon, at the mouth of which the first irrigation ditches are taken out; thence it flows in a general northwesterly direction about 10 miles to its junction with the Jordan River. The lands irrigated by the water diverted from this stream are at an elevation of from 4,250 to 5,000 feet above sea level.

CANALS AND DITCHES.

The location of canals and ditches diverting water from Big Cottonwood Creek, and of the lands irrigated, is shown on map accompanying this report. (Pl. XLV.) Cross sections and grades of the various canals and ditches are shown on Plate XLVI. None of these canals and ditches, except the Upper Canal, were surveyed or constructed by an engineer, and there is no regularity or uniformity in their cross sections or grades. Frequently the principal instrument used in laying out the ditches was a plow. Starting at the stream, a furrow would be plowed, following as nearly as possible a grade contour. After a short length of furrow had been plowed, water would be turned in from the creek. If the water ran to the lower end of the furrow it was assumed that the grade was all right, and the furrow was continued. If the water would not run the full length of the furrow, it was easy to locate and cut d[illegible] some instances an attempt to have a unif[illegible]tting grade pegs with a triangle and [illegible]el and straightedge,

and the ditches were supposed to have certain bottom widths. As a matter of fact, however, the cross section and grade of any given ditch varies between rather wide limits, as may readily be imagined from the methods of construction.

HISTORY OF ARBITRATION.

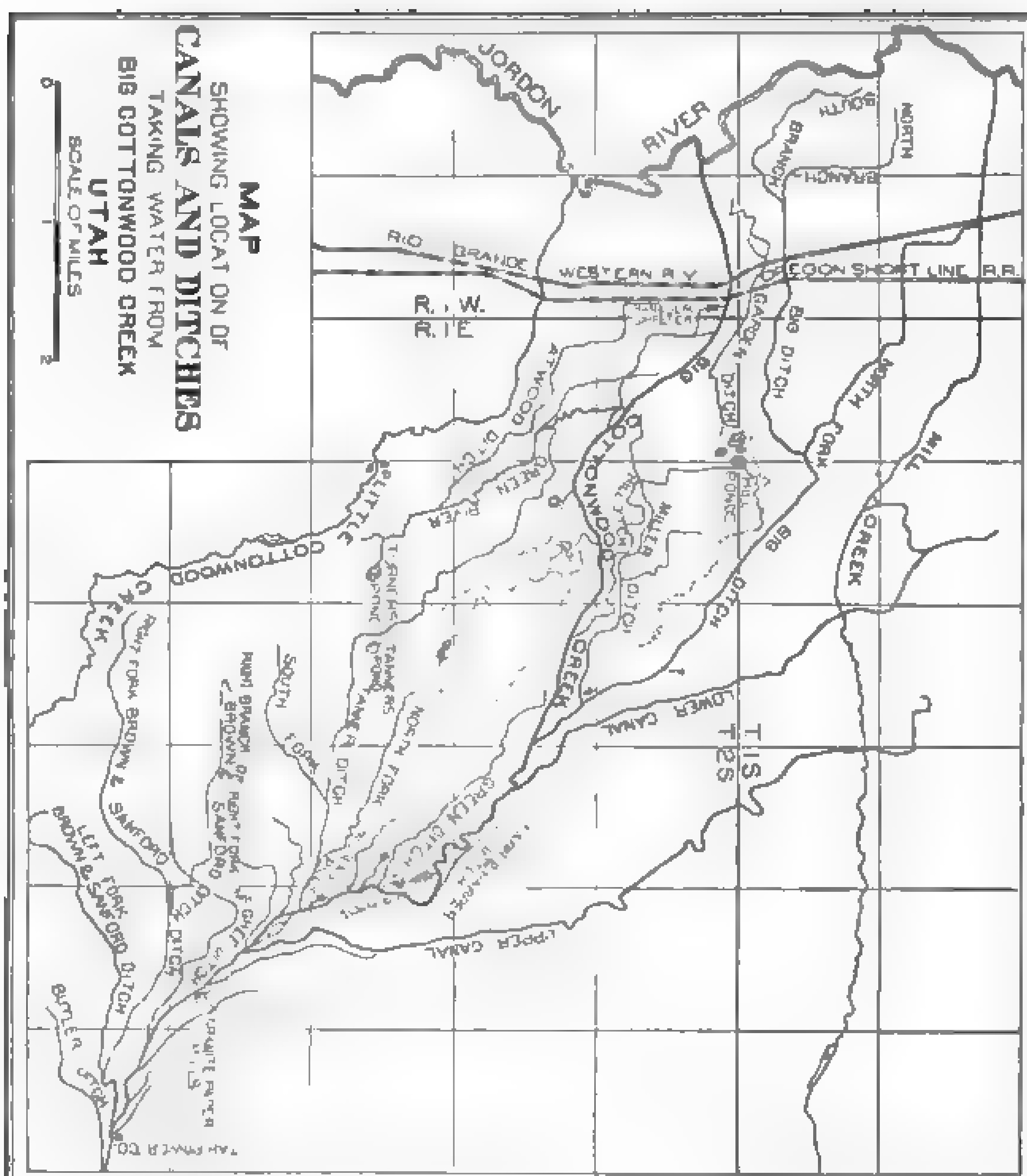
On September 13, 1879, the district court of the Territory of Utah appointed Joseph S. Rawlins, Reuben Miller, and D. B. Brinton, after they had previously been chosen by the water owners of Big Cottonwood Creek, a board of arbitrators to adjust all claims to the water of said creek and report its findings to said district court. This board, for convenience, divided the creek into 60 parts. One part would entitle its owner to irrigate 127.25 acres during time of low water. Each part, or share, was taken to mean one-sixtieth of the waters flowing in the creek at the highest point thereon where water is diverted by any of the canals or ditches mentioned in said agreement for arbitration. Only those holding primary rights were allotted shares during low-water season. The board classified the different canals and ditches, and parts, or shares, were allotted as follows:

Division of the water of Big Cottonwood Creek.

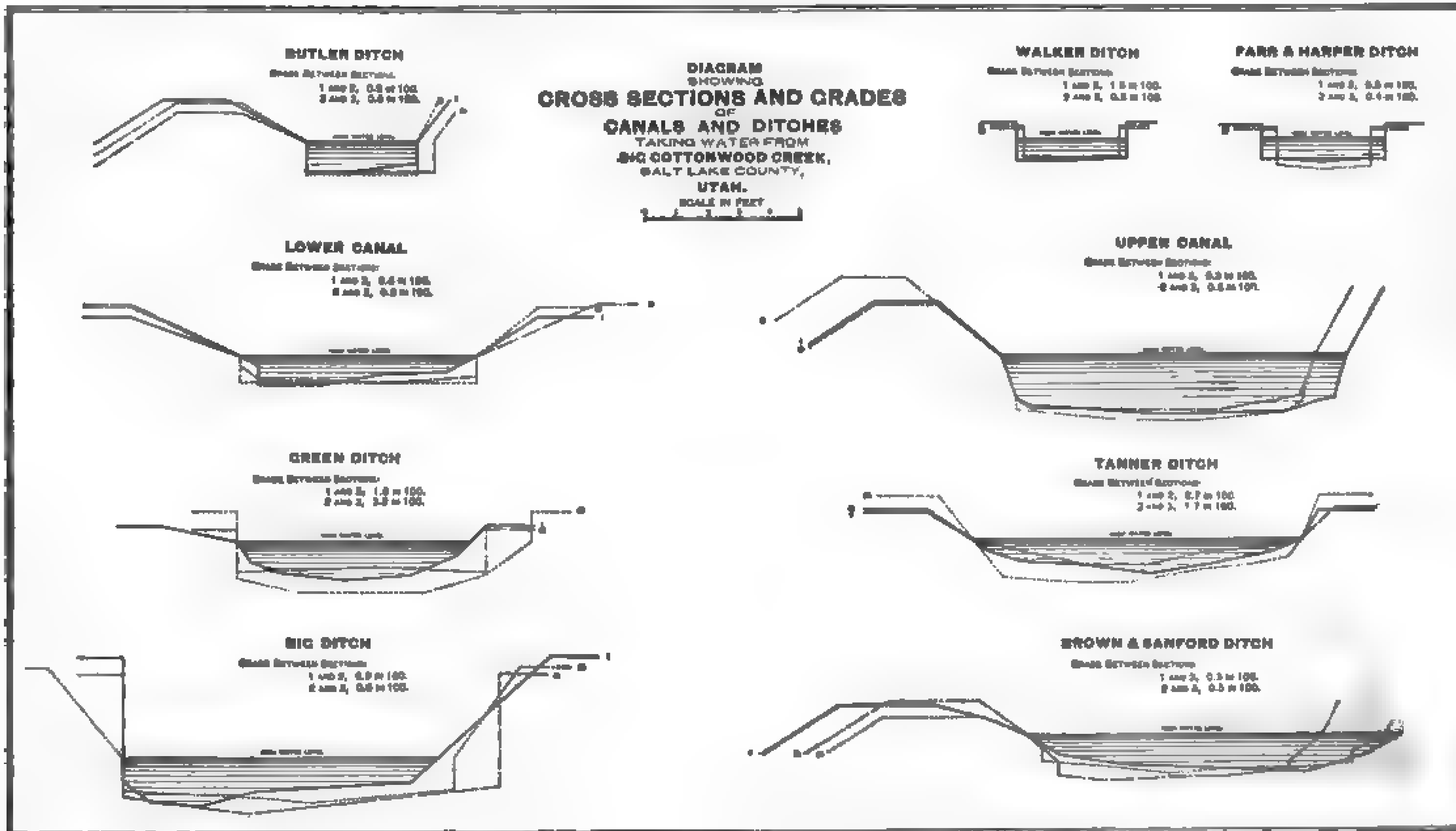
Class.	Name of ditch.	Number of parts.	
		January 1 to July 1.	July 1 to January 1.
1	Butler Ditch	0.5	0.2
2	Brown & Sanford Ditch	4.5	2.1
3	Upper Canal	10.5	10.2
4	Tanner Ditch	12.6	12.9
5	Green Ditch	3.5	3.8
6	Farr & Harper Ditch	.6	.6
7	Lower Canal	5.6	6.1
8	Big Ditch	19.6	21.3
9	Hill Ditch	2.6	2.8
	Total	60.0	60.0

A formal printed report showing the results of the action of the board of arbitration was made to the district court, and was properly filed. Each owner of a primary right in the stream was served with a written or printed notice of the arbitration, and a time was set by the court for hearing objections to said arbitration. No one appeared or objected, and the judgment of the court was rendered in accordance with the terms of the arbitration.

Nearly all of the owners of primary water rights appeared before the board of arbitrators and signed, under oath, an agreement to accept the division made by the board as binding and final. This agreement was properly filed with the district court, but has since disappeared and can not now be found. There were a few who did not sign this agreement, notably the Walker Brothers and a few owners on the Green Ditch. Others now claim that they did not sign the agreement,



Map Showing the Location of Canals and Ditches taking Water from Big Cottonwood Creek, Utah.



CROSS SECTIONS OF CANALS TAKING WATER FROM BIG COTTONWOOD CREEK, UTAH.

but the records of the proceedings of the board of arbitrators show that they did.

The division made by this board of arbitrators is supposed to be the basis upon which the water is divided, and is considered binding by all of the owners of primary rights, although those on the Green Ditch and part of the Tanner Ditch claim more water than was allotted to them by the board. As a matter of fact, the upper canals have always had more than their allotments and some of the lower canals less.

The following table shows the quantities of water actually diverted by six of the canals and ditches, together with the quantity that would have been diverted by each canal if the total quantity of water had been divided in accordance with the allotments of the board of arbitrators. During the season of 1899 there was an unusually large amount of water flowing in the creek, and, as there was an abundance of water for all, very little attention was paid to the manner of dividing it.

Table showing the quantity of water actually diverted by each canal during the irrigating season of 1899, together with the quantity that would have been diverted if the water had been divided in accordance with the allotments of the board of arbitrators.

[Flow given in cubic feet per second.]

Month.	Butler Ditch.		Brown & Sanford.		Upper Canal.		Green Ditch.		Lower Canal.		Big Ditch.	
	Allotted.	Diverted.	Allotted.	Diverted.	Allotted.	Diverted.	Allotted.	Diverted.	Allotted.	Diverted.	Allotted.	Diverted.
April	0.75	1.50	6.68	8.60	15.59	19.60	5.20	6.28	8.32	6.72	29.11	22.95
May	1.17	2.35	10.57	21.65	24.67	36.00	8.22	8.30	13.16	8.20	46.06	26.85
June	1.67	4.39	15.00	34.62	35.00	52.87	11.66	12.41	18.67	10.72	65.33	35.24
July	.51	3.73	5.31	25.24	25.77	44.08	9.60	4.45	15.41	6.91	53.83	28.02
August	.23	.93	2.40	6.84	11.72	15.13	4.36	8.38	7.00	4.90	24.48	14.01
September	.15	.49	1.58	4.32	7.70	10.06	2.87	7.63	4.60	2.11	16.07	8.36

The Big Ditch, Lower Canal, and Hill Ditch, being the last on the creek, claim that they have never received the amounts allotted by arbitration. As a water master on one of the upper canals naively remarked: "In high water they can't take it, and in low water they never get it. We take what we want and let them have the balance."

This division by arbitration was contested by suit in the third district court in 1891 and 1892 by the owners of the Green Ditch. In this suit they got judgment for enough water to irrigate 400 acres. Under this judgment they have usually taken all the water they needed, except at short intervals when the owners of the Big Ditch would shut off part of the water flowing into the Green Ditch and turn it down the creek.

It would seem that the root of all the trouble was the method pursued by the board of arbitration in making the division. It appears that the board did not make any measurements of lands irrigated under each ... ly called upon owners of primary rights to state ... cres they claimed water rights. The

acreage was footed up for each ditch and the division made upon that basis. People owning primary rights turned in the acreage they thought they had. Afterwards, when surveyed, it was found in some cases that they had not turned in enough. For instance, the people on the Upper Canal now claim that their allotment was about 100 acres short. In the case of the Big Ditch, other canals claim that the stockholders in the Big Ditch, in order that they might receive a large allotment of water by the arbitration, turned in all the land they had in the district, whether it had been irrigated or not. In that way much wet pasture land is said to have been listed, which they did not irrigate before and have not since. Again, it is claimed that much of the land turned in by owners on the Big Ditch was, and always has been, irrigated from springs.

The whole matter of division of the water seems to be in a very unsatisfactory condition. So much so that the troubles will probably culminate in a lawsuit involving all of the rights on the creek.

WATER RIGHTS.

The records used in making distribution of the water are those kept by the water masters. The water master of each ditch keeps a record of all the rights under his ditch, which is generally conceded to be correct by the owners on that particular ditch, but not necessarily so by the owners on other ditches.

The water master on a ditch is elected by the owners of water rights in the ditch, who hold a meeting annually for that purpose. The county commissioners used to appoint the water masters, but the district court ruled that they should be elected annually by the farmers themselves.

The ownership of water rights is based mainly upon the records of the water masters, each owner being supposed to have a right to water a certain number of acres. A right does not mean any certain quantity of water, nor does it mean any certain portion of the water flowing in the creek. This is owing to the manner in which the water is divided.

In the spring when the creek rises the upper ditches are filled full, and kept full as long as possible. If they do not take too much no objection is made, but if they take so much that the lower ditches do not get all they want, then the owners of the latter call for a division. Some seasons when there is a wet spring a division of the water is not necessary until July 1. Other years when there is a dry spring it may be necessary to have a division as early as in April. Users of surplus water are generally shut off on July 1, but it depends upon the season—that is, when the water in the creek gets low.

When the division is made the water masters of all the canals and ditches owning primary rights meet at the lowest point on the creek

WEIR AT THE HEAD OF BIG COTTONWOOD CREEK, UTAH.

where water is diverted, and proceed upstream, measuring the width and depth of water flowing at the head of each canal as they go. In this way the number of "square inches" flowing into each canal is obtained. These are added together to obtain the total number of "square inches" diverted. Then the water masters usually proceed downstream, regulating the quantities of water diverted, so that each canal will have its proper number of "square inches," according to the shares allotted by the arbitration, although this rule is not always closely followed. This regulation of the water holds good until another division is called for. They realize that there is nothing accurate about this method of measurement, but have always made it in that way. The measurement was usually made over a board at the head of the canal. This year it was made over Cippoletti weirs (Pl. XLVII). A stream 100 inches wide and 5 inches deep would be 500 "inches," according to their method, and a stream 50 inches wide and 10 inches deep would also be 500 "inches." No allowance is made for differences in velocity in the various canals. The upper ditches take out their full number of "inches," and the lower ditches take what they can get.

The division of the water among the owners of any ditch is made by the water master. A description of the ownership and method of dividing the water on the Brown & Sanford Ditch will serve as an illustration.

Ownership in the water goes by shares or "rods," each rod representing that length of the main ditch built by the first owners. The water master kept track of the construction work, calculated the acreage to which different ones were entitled according to such work, and made out certificates for the same. Usually the farmers do not form a regular company, but simply club together and furnish labor for the construction of the main ditch. Water enters all the main branches by self-dividing gates, the widths being proportioned to the shares, no attempt being made to attain accuracy. During low water these branches usually take turn about in carrying the full flow allowed to the main ditch, as the water will go much farther by thus using a large head.

For the individual owners on each main branch there is an allotment to each of the full flow for a certain number of hours, beginning at the one nearest the head and following down in regular order. Usually seven and one-half days or one hundred and eighty hours is the period for one rotation, the watering then beginning at the head again. Each owner's gate is fixed so that he can take the full flow, and his water ticket shows the date and number of hours he is entitled to all of the water, so that he can at once divert it when his time begins.
time the one above is to cease diverting it. Where th
among the owners, all this is done without ne
the part of the water master, his main

tickets of time for such distribution. The "rods" or shares are sometimes divided into quarters, and even smaller fractions, to suit the various holdings.

From what has been said it will be noted that it would not be easy to obtain a legally defined title to water on this stream, and that it would be impossible to determine how much water any given right represents.

STUDIES OF DUTY OF WATER IN 1899.

Instructions to measure the water diverted from Big Cottonwood Creek by canals and ditches were not received until about June 1, 1899. As soon as possible thereafter, Cippoletti trapezoidal weirs were put in the canals and ditches at points near the headgates, and the measurements were begun. It required considerable persuasion in some instances to obtain permission to put in the weirs. There has been more or less friction among the owners of the various canals and ditches, and some of them did not want the water measured at all. The owners of the Tanner Ditch would not allow a weir to be put in where all of the water they diverted could be measured. During part of the season they ran water from the creek through a small branch, turning it into their ditch at a point about 50 yards below the weir. At the time the weir was put in owners of other ditches said they would shut off this branch, claiming that the Tanner Ditch had no right to take water through it; but this was not done until the creek had fallen to low-water stage. The measurements made in the Tanner Ditch are, therefore, of little or no value. The weir on the Farr & Harper Ditch was torn out by the ditch owners after being in only one day, and arrangements were not completed for replacing it until early in July. Most of the water measured in the Walker Ditch was merely run through a fish pond, only a small portion of it being used for irrigating purposes.

The heads on the weirs were measured once a day with a hook gage. Probably the heads should have been measured at least twice a day, as there is generally a slight variation between morning and evening in the discharge of the creek. But as the weir measurements were made at all hours of the day, and not at any particular time for each ditch, it is believed that a fair average of the flow was obtained.

In order to calculate the duty of water it has been necessary to estimate the flow in the canals and ditches during April, May, and the early part of June. In doing this use has been made of gagings of the discharge of the creek. These gagings were made by Mr. F. C. Kelsey, city engineer of Salt Lake City, over a Cippoletti weir, the head being measured twice a day with a hook gage. The estimates of flow in canals and ditches during that part of the irrigating season when weir measurements were not taken have been thoughtfully and

carefully made, and it is believed that they are pretty close to the truth. For reasons previously stated, no attempt has been made to calculate the duty of water under the Tanner, Farr & Harper, or Walker ditches.

The irrigating season usually begins about April 15 and ends about September 30. The date when irrigating is begun varies with the seasons; with a dry spring it may begin as early as April 1, and with a wet spring it may begin as late as May 1.

During the winter of 1898–99 there was an unusually heavy snowfall in the mountains on the drainage area tributary to this creek. For this reason there was an abundance of water for all ditches during the early part of the irrigating season, and it is believed that more water was taken out then than was needed, and that the duty of water was therefore lower than usual.

The following table shows the precipitation as recorded by the Weather Bureau at Salt Lake City:

Precipitation at Salt Lake City, Utah, October, 1898, to September, 1899.

Month.	Rainfall.	Above normal.	Below normal.
1898.	*Inches.*	*Inches.*	*Inches.*
October	1.57	0.03	
November	1.95	.59	
December	1.28		0.36
1899.			
January	.84		.60
February	2.98	1.70	
March	2.93	.90	
April	.81		1.40
May	2.59	.87	
June	.96	.17	
July	.42		.11
August	1.06	.34	
September			.23
Total	17.39	4.60	2.70

From the above table it will be noted that the precipitation from October, 1898, to March, 1899, inclusive, was 2.26 inches in excess of the normal; while during the irrigating season, from April to September, 1899, inclusive, it was 0.36 inch below the normal.

In order to make an intelligent comparison of the duty of water under the various canals it is necessary to know what kinds of lands were irrigated in each case. As a general statement it may be said that bench land requires about 50 per cent more water than bottom land.

BUTLER DITCH.

The acr ... ted by the Butler Ditch is all sandy, gravelly be ... h water. The area irrigated under this d ... ing table shows the daily use of water ... April 15, when irrigation began, to

September 30, when irrigation closed. The flow from April 15 to June 8 is estimated, as previously explained:

Water used in irrigating lands under the Butler Ditch, 1899.

[See diagram, Pl. XIII, p. 74.]

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	.....	4.6611	5.1570	9.5207	1.7851	0.7934
2		4.6611	5.1570	9.5207	1.7851	.7934
3		4.6611	5.1570	9.7190	2.7769	.5950
4		4.6611	5.1570	9.9174	5.5537	.7934
5		4.6611	5.1570	9.9174	6.1488	.5950
6		4.6611	5.1570	10.1157	5.5537	.5950
7		4.6611	5.1570	10.3140	4.3636	.7934
8		4.6611	5.1570	10.5124	3.1736	.9917
9		4.6611	5.1570	9.7190	1.9835	.7934
10		4.6611	5.9504	10.7107	1.9835	.9917
11		4.6611	6.7438	9.9174	1.7851	1.1901
12		4.6611	7.5372	10.7107	1.7851	1.1901
13	.....	4.6611	8.3306	9.7190	2.3802	1.3884
14	.....	4.6611	9.1240	11.9008	2.1818	1.3884
15	2.9752	4.6611	9.9174	7.5372	1.1901	1.1901
16	2.9752	4.6611	10.7107	12.4959	1.3884	.9917
17	2.9752	4.6611	11.1074	7.1405	1.1901	.7934
18	2.9752	4.6611	11.7025	5.5537	.9917	.9917
19	2.9752	4.6611	11.7025	6.3471	.7934	.7934
20	2.9752	4.6611	13.4876	4.1653	.5950	.7934
21	2.9752	4.6611	13.0909	3.5702	.5950	.9917
22	2.9752	4.6611	12.6942	3.7686	....	.9917
23	2.9752	4.6611	11.5041	3.9669	....	.7934
24	2.9752	4.6611	10.7107	3.7686	....	.7934
25	2.9752	4.6611	11.9008	5.3554	.7934	1.3884
26	2.9752	4.6611	10.9091	5.5537	.5950	1.3884
27	2.9752	4.6611	9.7190	5.3554	1.1901	1.1901
28	2.9752	4.6611	9.5207	3.5702	.9917	1.1901
29	2.9752	4.6611	9.3223	3.7686	1.3884	.9917
30	2.9752	4.6611	9.3223	3.5702	1.1901	.9917
31		4.6611	....	1.7851	.9917	....
Total	47.6032	144.4941	261.4212	229.4875	57.1298	29.1567

Duty of water under the Butler Ditch, 1899.

Month.	Area.[1]	Water used. Quantity.	Water used. Depth.	Area per cubic foot per second.[2]
	Acres.	*Acre-feet.*	*Feet.*	*Acres.*
April	123.5	47.6032	0.39	....
May	123.5	144.4941	1.17	....
June	123.5	261.4212	2.12	....
July	123.5	229.4875	1.86	....
August	123.5	57.1298	.46	....
September	123.5	29.1567	.24	....
Total irrigation	....	769.2865	6.24	83.72
Rainfall	....	....	.49	....
Total water received	....	....	6.73	....

[1] It is impossible to tell just how much of the land under the canal is irrigated each month. For the purpose of computing the depth of water used, the whole area is assumed to have been irrigated each month.

[2] Continuous flow for 169 days.

BROWN & SANFORD DITCH.

The acreage under the Brown & Sanford Ditch is nearly all sandy, gravelly bench land, requiring much water. The area irrigated is 1,108.5 acres. The following table shows the daily flow of this ditch from April 15 to September 30, the period during which water was used in irrigation. The flow from April 15 to June 15 is estimated.

Water used in irrigating lands under the Brown & Sanford Ditch, 1899.

[See diagram, Pl. XII, p. 74.]

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		42.9421	67.3851	69.0248	16.8595	8.5289
2		42.9421	67.3851	69.0248	15.2727	8.9256
3		42.9421	67.3851	69.2231	17.2562	8.9256
4		42.9421	67.3851	69.2231	22.0165	8.5289
5		42.9421	67.3851	69.4215	19.8347	8.1322
6		42.9421	67.3851	69.4215	18.2479	7.7355
7		42.9421	67.3851	69.6198	17.8512	8.1322
8		42.9421	67.3851	69.6198	17.8512	8.5289
9		42.9421	67.3851	65.0578	17.8512	8.5289
10		42.9421	67.3851	66.4463	17.2562	8.1322
11		42.9421	67.3851	64.2645	16.8595	8.9256
12		42.9421	67.3851	70.4132	17.2562	8.5289
13		42.9421	67.3851	55.9339	15.2727	8.9256
14		42.9421	67.3851	69.6198	13.4876	10.7107
15	17.0579	42.9421	67.3851	48.5950	14.8760	10.7107
16	17.0579	42.9421	65.6529	52.1654	14.8760	10.3140
17	17.0579	42.9421	68.0301	42.4463	13.4876	9.9174
18	17.0579	42.9421	70.4132	41.0578	12.8926	8.1322
19	17.0579	42.9421	71.4050	45.0248	12.8926	8.5289
20	17.0579	42.9421	73.5868	42.4463	12.4957	8.5289
21	17.0579	42.9421	74.3802	44.4298	8.5289	8.1322
22	17.0579	42.9421	71.4050	42.4463	8.5289	8.1322
23	17.0579	42.9421	65.6529	43.0413	10.3140	8.5289
24	17.0579	42.9421	74.3802	42.4463	10.3140	8.1322
25	17.0579	42.9421	72.1983	29.5537	8.5289	6.7438
26	17.0579	42.9421	67.4380	28.9587	8.9256	6.7438
27	17.0579	42.9421	69.6198	31.9339	8.5289	7.7355
28	17.0579	42.9421	67.4380	18.2479	12.0992	8.1322
29	17.0579	42.9421	68.8264	17.8512	5.5537	8.5289
30	17.0579	42.9421	68.8264	17.2562	6.3471	8.9256
31		42.9421		17.8512	8.1322	
Total	272.9264	1,331.2051	2,060.0297	1,552.0660	420.4952	257.0571

Duty of water under Brown & Sanford Ditch, 1899.

Month.	Area.[1]	Water used. Quantity.	Water used. Depth.	Area per cubic foot per second.[2]
	Acres.	*Acre-feet.*	*Feet.*	*Acres.*
April	1,108.5	272.9264	0.25	
May	1,108.5	1,331.2051	1.20	
June	1,108.5	2,060.0297	1.86	
July	1,108.5	1,552.0660	1.40	
August	1,108.5	420.4952	.38	
September	1,108.5	257.0571	.23	
Total irrigation		5,893.7795	5.32	63.01
Rainfall			.49	
Total water received			5.81	

[1] For the purpose of estimating depth of water used, the whole area is assumed to have been irrigated each month.
[2] Continuous flow for 169 days.

UPPER CANAL.

Under the Upper Canal about 300 acres is sandy, gravelly bench land, about 1,200 acres is clayey bench land, not requiring quite so much water as the gravelly bench land, and about 90 acres is bottom land, requiring than the clayey bench land. The total area is 1, ig table shows the daily use of water on thes l from April 20 to June 3 is estimated.

Water used in irrigating lands under the Upper Canal, 1899.

[See diagram, Pl. X, p. 74.]

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	71.4050	103.1402	104.9256	37.8843	23.2066
2	....	71.4050	105.1237	104.3306	39.8678	19.2397
3	....	71.4050	107.1072	103.7355	39.2727	18.2479
4	....	71.4050	116.0331	103.1405	47.2066	21.0248
5	....	71.4050	111.4711	102.5455	37.0909	19.2397
6	....	71.4050	107.1074	101.9504	36.4959	23.2066
7	....	71.4050	107.7025	101.3554	37.8843	24.3967
8	....	71.4050	108.4959	102.3471	37.4876	23.8017
9	....	71.4050	109.0909	108.0992	37.0909	23.2066
10	....	71.4050	109.8843	105.1240	36.4959	23.8017
11	....	71.4050	110.4793	108.0992	34.5124	21.6198
12	....	71.4050	111.2727	107.1074	34.1157	19.2397
13	....	71.4050	111.8678	107.1074	31.1405	18.2479
14	....	71.4050	112.6612	97.5868	26.7769	19.2397
15	....	71.4050	113.4545	98.5785	27.3719	18.8430
16	....	71.4050	114.0496	108.3388	26.7769	18.2479
17	....	71.4050	121.9835	85.0859	26.7769	19.2397
18	....	71.4050	101.3551	89.2562	24.9917	21.6198
19	....	71.4050	102.3471	89.2562	24.3967	19.2397
20	38.8760	71.4050	103.3388	85.6859	23.8017	18.8430
21	38.8760	71.4050	103.3388	84.6942	24.9917	19.2397
22	38.8760	71.4050	83.9008	83.9008	24.3967	18.8430
23	38.8760	71.4050	89.2562	84.6942	22.2149	19.2397
24	38.8760	71.4050	83.9008	79.3388	24.9917	18.8430
25	38.8760	71.4050	84.6942	68.2314	24.9917	17.6529
26	38.8760	71.4050	101.3551	60.0992	24.3967	18.2479
27	38.8760	71.4050	102.3471	60.0992	24.9917	17.6529
28	38.8760	71.4050	97.5868	47.8017	24.9917	18.2479
29	38.8760	71.4050	106.1157	47.2066	23.2066	18.8430
30	38.8760	71.4050	105.5207	44.2314	24.3967	18.2479
31	....	71.4050	....	40.6612	19.2397	....
Total	427.6360	2,213.5550	3,145.9827	2,710.2148	930.2480	598.8101

Duty of water under the Upper Canal, 1899.

Month.	Area.[1]	Water used. Quantity.	Water used. Depth.	Area per cubic foot per second.[2]
	Acres.	*Acre-feet.*	*Feet.*	*Acres.*
April	1,590.5	427.6360	0.27	....
May	1,590.5	2,213.5550	1.39	....
June	1,590.5	3,145.9827	1.98	....
July	1,590.5	2,710.2148	1.70	....
August	1,590.5	930.2480	.58	....
September	1,590.5	598.8101	.38	....
Total irrigation	....	10,026.4466	6.30	51.63
Rainfall	....	....	.49	....
Total water received	....	....	6.79	....

[1] For the purpose of computing the depth of water used, the whole area is assumed to have been irrigated each month.
[2] Continuous flow for 164 days.

GREEN DITCH.

The acreage under the Green Ditch is all bottom land. About 200 acres of it is gravelly land, requiring much water; the remainder is rich, loamy soil, requiring less water. The total area irrigated under this ditch is 586.25 acres. The daily use of water is shown by the following table. The flow from A estimated.

Water used in irrigating lands under the Green Ditch, 1899.

[See diagram, Pl. XIV, p. 74.]

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		16.4628	19.8347	17.0579	8.7273	12.4959
2		16.4628	19.8347	15.8678	6.1488	12.4959
3		16.4628	19.8347	14.4793	5.7521	12.0992
4		16.4628	19.8347	13.2893	6.1488	11.7025
5		16.4628	24.1983	11.9008	5.7521	12.0992
6		16.4628	23.0083	10.5124	5.5537	11.7025
7		16.4628	21.6198	9.1240	4.7603	10.7107
8		16.4628	22.6116	6.3471	15.8678	16.6612
9		16.4628	23.6033	9.5207	26.9752	17.8512
10		16.4628	24.5950	9.5207	26.1818	18.4463
11		16.4628	25.5868	3.7686	25.1901	18.4463
12		16.4628	26.5785	6.1488	24.7934	17.8512
13		16.4628	27.5702	6.3471	24.7934	17.8512
14		16.4628	28.5620	8.7273	24.1983	18.4463
15		16.4628	29.5537	6.1488	24.7934	18.4463
16		16.4628	33.9174	12.0992	23.8017	17.8512
17		16.4628	38.2810	8.7273	22.0165	17.4545
18		16.4628	42.4463	10.3140	21.0248	17.8512
19		16.4628	33.3213	10.7107	20.4298	17.8512
20	12.4562	16.4628	32.3306	7.1405	19.8347	16.6612
21	12.4562	16.4628	31.3388	6.1488	19.8347	15.4711
22	12.4562	16.4628	30.5455	6.1488	19.4380	14.2810
23	12.4562	16.4628	25.3884	6.3471	16.6612	14.2810
24	12.4562	16.4628	24.7934	6.3471	16.2645	13.8843
25	12.4562	16.4628	21.2231	6.1488	16.2645	12.8926
26	12.4562	16.4628	9.5207	3.7686	15.8678	12.8926
27	12.4562	16.4628	8.5289	3.5702	14.6777	13.0909
28	12.4562	16.4628	11.7025	10.7107	13.8843	13.8843
29	12.4562	16.4628	19.6364	9.1240	13.8843	13.8843
30	12.4562	16.4628	18.4462	9.1240	13.0909	14.2810
31		16.4628		8.7273	12.8926	
Total	137.0182	510.3468	754.5116	273.9177	515.5045	453.8183

Duty of water under the Green Ditch, 1899.

Month.	Area.[1]	Water used.		Area per cubic foot per second.[2]
		Quantity.	Depth.	
	Acres.	*Acre-feet.*	*Feet.*	*Acres.*
April	586.25	137.0182	0.23	
May	586.25	510.3468	.87	
June	586.25	754.5116	1.30	
July	586.25	273.9177	.47	
August	586.25	515.5045	.88	
September	586.25	453.8183	.77	
Total irrigation		2,645.1171	4.52	71.97
Rainfall			.49	
Total water received			5.01	

[1] For the purpose of estimating the depth of water used, the whole area is assumed to have been irrigated each month.
[2] Continuous flow for 164 days.

LOWER CANAL.

The acreage under the Lower Canal is all bottom land. It is all good, rich soil except that which has become swampy by irrigation above. The pasture land is watered only once or twice during the irrigating
A number of small springs, caused by seepage from higher
ds, rise on this land, and serve to slightly increase the cal-
they were not taken into account in the water meas-
are 717.25 acres irrigated from this canal. The

acreage was footed up for each ditch and the division made upon that basis. People owning primary rights turned in the acreage they thought they had. Afterwards, when surveyed, it was found in some cases that they had not turned in enough. For instance, the people on the Upper Canal now claim that their allotment was about 100 acres short. In the case of the Big Ditch, other canals claim that the stockholders in the Big Ditch, in order that they might receive a large allotment of water by the arbitration, turned in all the land they had in the district, whether it had been irrigated or not. In that way much wet pasture land is said to have been listed, which they did not irrigate before and have not since. Again, it is claimed that much of the land turned in by owners on the Big Ditch was, and always has been, irrigated from springs.

The whole matter of division of the water seems to be in a very unsatisfactory condition. So much so that the troubles will probably culminate in a lawsuit involving all of the rights on the creek.

WATER RIGHTS.

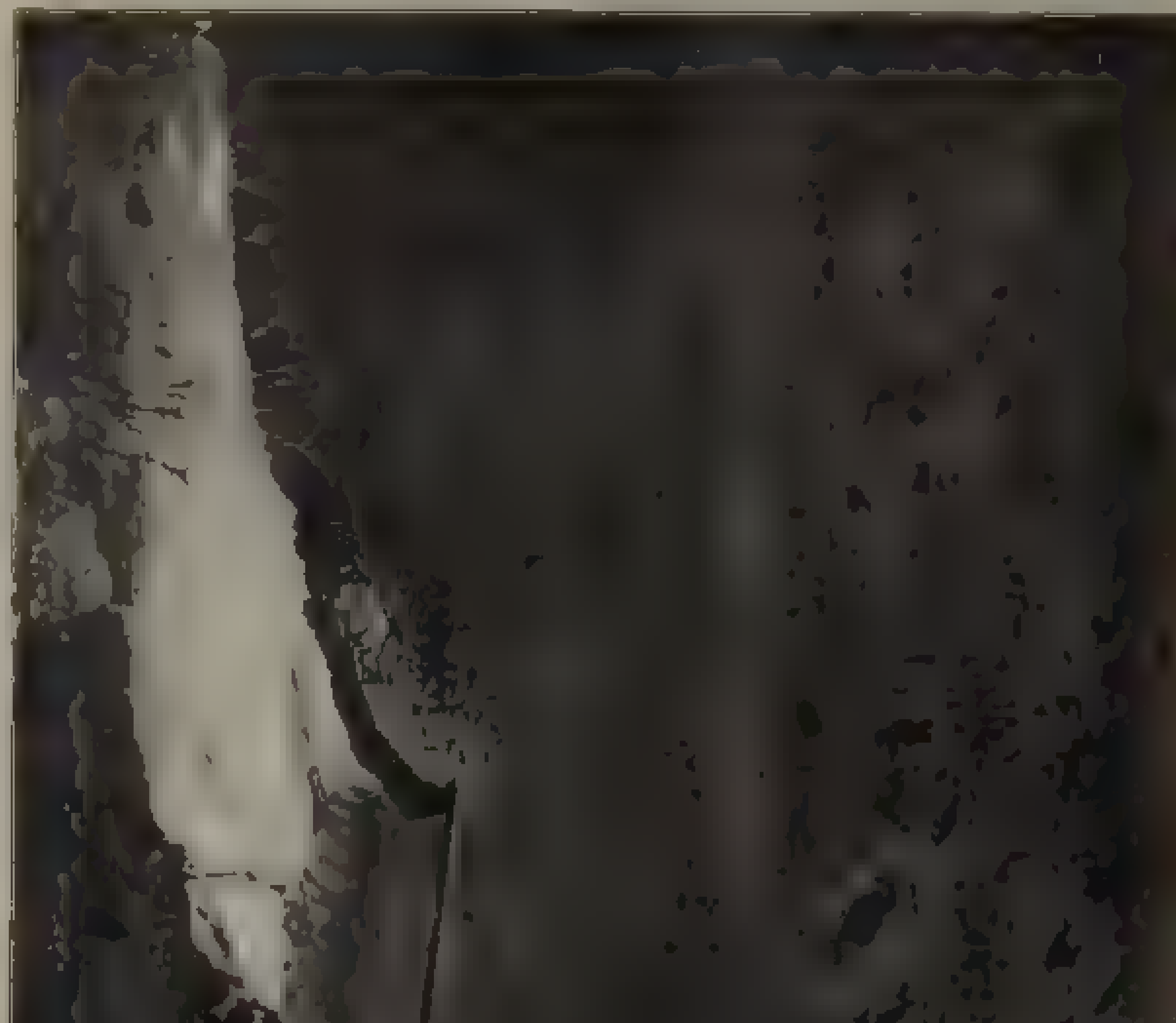
The records used in making distribution of the water are those kept by the water masters. The water master of each ditch keeps a record of all the rights under his ditch, which is generally conceded to be correct by the owners on that particular ditch, but not necessarily so by the owners on other ditches.

The water master on a ditch is elected by the owners of water rights in the ditch, who hold a meeting annually for that purpose. The county commissioners used to appoint the water masters, but the district court ruled that they should be elected annually by the farmers themselves.

The ownership of water rights is based mainly upon the records of the water masters, each owner being supposed to have a right to water a certain number of acres. A right does not mean any certain quantity of water, nor does it mean any certain portion of the water flowing in the creek. This is owing to the manner in which the water is divided.

In the spring when the creek rises the upper ditches are filled full, and kept full as long as possible. If they do not take too much no objection is made, but if they take so much that the lower ditches do not get all they want, then the owners of the latter call for a division. Some seasons when there is a wet spring a division of the water is not necessary until July 1. Other years when there is a dry spring it may be necessary to have a division as early as in April. Users of surplus water are generally shut off on July 1, but it depends upon the season—that is, when the water in the creek gets low.

When the division is made the water masters of all the canals and ditches owning primary rights meet at the lowest point on the creek



WEIR AT THE HEAD OF BIG COTTONWOOD CREEK, UTAH.

where water is diverted, and proceed upstream, measuring the width and depth of water flowing at the head of each canal as they go. In this way the number of "square inches" flowing into each canal is obtained. These are added together to obtain the total number of "square inches" diverted. Then the water masters usually proceed downstream, regulating the quantities of water diverted, so that each canal will have its proper number of "square inches," according to the shares allotted by the arbitration, although this rule is not always closely followed. This regulation of the water holds good until another division is called for. They realize that there is nothing accurate about this method of measurement, but have always made it in that way. The measurement was usually made over a board at the head of the canal. This year it was made over Cippoletti weirs (Pl. XLVII). A stream 100 inches wide and 5 inches deep would be 500 "inches," according to their method, and a stream 50 inches wide and 10 inches deep would also be 500 "inches." No allowance is made for differences in velocity in the various canals. The upper ditches take out their full number of "inches," and the lower ditches take what they can get.

The division of the water among the owners of any ditch is made by the water master. A description of the ownership and method of dividing the water on the Brown & Sanford Ditch will serve as an illustration.

Ownership in the water goes by shares or "rods," each rod representing that length of the main ditch built by the first owners. The water master kept track of the construction work, calculated the acreage to which different ones were entitled according to such work, and made out certificates for the same. Usually the farmers do not form a regular company, but simply club together and furnish labor for the construction of the main ditch. Water enters all the main branches by self-dividing gates, the widths being proportioned to the shares, no attempt being made to attain accuracy. During low water these branches usually take turn about in carrying the full flow allowed to the main ditch, as the water will go much farther by thus using a large head.

For the individual owners on each main branch there is an allotment to each of the full flow for a certain number of hours, beginning at the one nearest the head and following down in regular order. Usually seven and one-half days or one hundred and eighty hours is the period for one rotation, the watering then beginning at the head again. Each owner's gate is fixed so that he can take the full flow, and his water ticket shows the date and number of hours he is entitled to all of the water, so that he can at once divert it when his time begins, at which time the one above is to cease diverting it. Where there is harmony among the owners, all this is done without need of superintendence on the part of the water master, his main work being in making out the

tickets of time for such distribution. The "rods" or shares are sometimes divided into quarters, and even smaller fractions, to suit the various holdings.

From what has been said it will be noted that it would not be easy to obtain a legally defined title to water on this stream, and that it would be impossible to determine how much water any given right represents.

STUDIES OF DUTY OF WATER IN 1899.

Instructions to measure the water diverted from Big Cottonwood Creek by canals and ditches were not received until about June 1, 1899. As soon as possible thereafter, Cippoletti trapezoidal weirs were put in the canals and ditches at points near the headgates, and the measurements were begun. It required considerable persuasion in some instances to obtain permission to put in the weirs. There has been more or less friction among the owners of the various canals and ditches, and some of them did not want the water measured at all. The owners of the Tanner Ditch would not allow a weir to be put in where all of the water they diverted could be measured. During part of the season they ran water from the creek through a small branch, turning it into their ditch at a point about 50 yards below the weir. At the time the weir was put in owners of other ditches said they would shut off this branch, claiming that the Tanner Ditch had no right to take water through it; but this was not done until the creek had fallen to low-water stage. The measurements made in the Tanner Ditch are, therefore, of little or no value. The weir on the Farr & Harper Ditch was torn out by the ditch owners after being in only one day, and arrangements were not completed for replacing it until early in July. Most of the water measured in the Walker Ditch was merely run through a fish pond, only a small portion of it being used for irrigating purposes.

The heads on the weirs were measured once a day with a hook gage. Probably the heads should have been measured at least twice a day, as there is generally a slight variation between morning and evening in the discharge of the creek. But as the weir measurements were made at all hours of the day, and not at any particular time for each ditch, it is believed that a fair average of the flow was obtained.

In order to calculate the duty of water it has been necessary to estimate the flow in the canals and ditches during April, May, and the early part of June. In doing this use has been made of gagings of the discharge of the creek. These gagings were made by Mr. F. C. Kelsey, city engineer of Salt Lake City, over a Cippoletti weir, the head being measured twice a day with a hook gage. The estimates of flow in canals and ditches during that part of the irrigating season when weir measurements were not taken have been thoughtfully and

carefully made, and it is believed that they are pretty close to the truth. For reasons previously stated, no attempt has been made to calculate the duty of water under the Tanner, Farr & Harper, or Walker ditches.

The irrigating season usually begins about April 15 and ends about September 30. The date when irrigating is begun varies with the seasons; with a dry spring it may begin as early as April 1, and with a wet spring it may begin as late as May 1.

During the winter of 1898–99 there was an unusually heavy snowfall in the mountains on the drainage area tributary to this creek. For this reason there was an abundance of water for all ditches during the early part of the irrigating season, and it is believed that more water was taken out then than was needed, and that the duty of water was therefore lower than usual.

The following table shows the precipitation as recorded by the Weather Bureau at Salt Lake City:

Precipitation at Salt Lake City, Utah, October, 1898, to September, 1899.

Month.	Rainfall.	Above normal.	Below normal.
1898.	*Inches.*	*Inches.*	*Inches.*
October	1.57	0.03	
November	1.95	.59	
December	1.28		0.36
1899.			
January	.84		.60
February	2.98	1.70	
March	2.93	.90	
April	.81		1.40
May	2.59	.87	
June	.96	.17	
July	.42		.11
August	1.06	.34	
September			.23
Total	17.39	4.60	2.70

From the above table it will be noted that the precipitation from October, 1898, to March, 1899, inclusive, was 2.26 inches in excess of the normal; while during the irrigating season, from April to September, 1899, inclusive, it was 0.36 inch below the normal.

In order to make an intelligent comparison of the duty of water under the various canals it is necessary to know what kinds of lands were irrigated in each case. As a general statement it may be said that bench land requires about 50 per cent more water than bottom land.

BUTLER DITCH.

The acreage irrigated by the Butler Ditch is all sandy, gravelly bench land, requiring much water. The area irrigated under this ditch is 123.5 acres. The following table shows the daily use of water on lands under this ditch from April 15, when irrigation began, to

September 30, when irrigation closed. The flow from April 15 to June 8 is estimated, as previously explained:

Water used in irrigating lands under the Butler Ditch, 1899.

[See diagram, Pl. XIII, p. 74.]

Day	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		4.6611	5.1570	9.5207	1.7851	0.7934
2		4.6611	5.1570	9.5207	1.7851	.7934
3		4.6611	5.1570	9.7190	2.7769	.5950
4		4.6611	5.1570	9.9174	5.5537	.7934
5		4.6611	5.1570	9.9174	6.1488	.5950
6		4.6611	5.1570	10.1157	5.5537	.5950
7		4.6611	5.1570	10.3140	4.7603	.7934
8		4.6611	5.1570	10.5124	3.1736	.9917
9		4.6611	5.1570	9.7190	1.9835	.7934
10		4.6611	5.9504	10.7107	1.9835	.9917
11		4.6611	6.7438	9.9174	1.7851	1.1901
12		4.6611	7.5372	10.7107	1.7851	1.1901
13		4.6611	8.3306	9.7190	2.3802	1.3884
14		4.6611	9.1240	11.9008	2.1818	1.3884
15	2.9752	4.6611	9.9174	7.5372	1.1901	1.1901
16	2.9752	4.6611	10.7107	12.4960	1.3884	.9917
17	2.9752	4.6611	11.1074	7.1405	1.1901	.7934
18	2.9752	4.6611	11.7025	5.5537	.9917	.9917
19	2.9752	4.6611	11.7025	6.3471	.7934	.7934
20	2.9752	4.6611	13.4876	4.1653	.5950	.7934
21	2.9752	4.6611	13.0909	3.5702	.5950	.9917
22	2.9752	4.6611	12.6942	3.7686	....	.9917
23	2.9752	4.6611	11.5041	3.9669	....	.7934
24	2.9752	4.6611	10.7107	3.7686	....	.7934
25	2.9752	4.6611	11.9008	5.3554	.7934	1.3884
26	2.9752	4.6611	10.9091	5.5537	.5950	1.3884
27	2.9752	4.6611	9.7190	5.3554	1.1901	1.1901
28	2.9752	4.6611	9.5207	3.5702	.9917	1.1901
29	2.9752	4.6611	9.3223	3.7686	1.3884	.9917
30	2.9752	4.6611	9.3223	3.5702	1.1901	.9917
31		4.6611	....	1.7851	.9917	....
Total	47.6032	144.4941	261.4212	229.4675	57.1290	29.1567

Duty of water under the Butler Ditch, 1899.

Month	Area.[1]	Water used. Quantity.	Water used. Depth.	Area per cubic foot per second.[2]
	Acres.	*Acre-feet.*	*Feet.*	*Acres.*
April	123.5	47.6032	0.39	....
May	123.5	144.4941	1.17	....
June	123.5	261.4212	2.12	....
July	123.5	229.4675	1.86	....
August	123.5	57.1290	.46	....
September	123.5	29.1567	.24	....
Total irrigation	....	769.2865	6.24	83.72
Rainfall	....	....	.49	....
Total water received	....	....	6.73	....

[1] It is impossible to tell just how much of the land under the canal is irrigated each month. For the purpose of computing the depth of water used, the whole area is assumed to have been irrigated each month.

[2] Continuous flow for 169 days.

BROWN & SANFORD DITCH.

The acreage under the Brown & Sanford Ditch is nearly all sandy, gravelly bench land, requiring much water. The area irrigated is 1,108.5 acres. The following table shows the daily flow of this ditch from April 15 to September 30, the period during which water was used in irrigation. The flow from April 15 to June 15 is estimated.

Water used in irrigating lands under the Brown & Sanford Ditch, 1899.

[See diagram, Pl. XII, p. 74.]

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1		42.9421	67.3851	69.0248	16.8595	8.5289
2		42.9421	67.3851	69.0248	15.2727	8.9256
3		42.9421	67.3851	69.2231	17.2562	8.9256
4		42.9421	67.3851	69.2231	22.0165	8.5289
5		42.9421	67.3851	69.4215	19.8347	8.1322
6		42.9421	67.3851	69.4215	18.2479	7.7355
7		42.9421	67.3851	69.6198	17.8512	8.1322
8		42.9421	67.3851	69.6198	17.8512	8.5289
9		42.9421	67.3851	65.0578	17.8512	8.5289
10		42.9421	67.3851	66.4463	17.2562	8.1322
11		42.9421	67.3851	64.2645	16.8595	8.9256
12		42.9421	67.3851	70.4132	17.2562	8.5289
13		42.9421	67.3851	55.9339	15.2727	8.9256
14		42.9421	67.3851	69.6198	13.4876	10.7107
15	17.0579	42.9421	67.3851	48.5950	14.8760	10.7107
16	17.0579	42.9421	65.6529	52.1654	14.8760	10.3140
17	17.0579	42.9421	68.0301	42.4463	13.4876	9.9174
18	17.0579	42.9421	70.4132	41.0578	12.8926	8.1322
19	17.0579	42.9421	71.4050	45.0248	12.8926	8.5289
20	17.0579	42.9421	73.5868	42.4463	12.4957	8.5289
21	17.0579	42.9421	74.3802	44.4298	8.5289	8.1322
22	17.0579	42.9421	71.4050	42.4463	8.5289	8.1322
23	17.0579	42.9421	65.6529	43.0413	10.3140	8.5289
24	17.0579	42.9421	74.3802	42.4463	10.3140	8.1322
25	17.0579	42.9421	72.1983	29.5537	8.5289	6.7438
26	17.0579	42.9421	67.4380	28.9587	8.9256	6.7438
27	17.0579	42.9421	69.6198	31.9339	8.5289	7.7355
28	17.0579	42.9421	67.4380	18.2479	12.0992	8.1322
29	17.0579	42.9421	68.8264	17.8512	5.5537	8.5289
30	17.0579	42.9421	68.8264	17.2562	6.3471	8.9256
31		42.9421		17.8512	8.1322	
Total	272.9264	1,331.2051	2,060.0297	1,552.0660	420.4952	257.0571

Duty of water under Brown & Sanford Ditch, 1899.

Month.	Area.[1]	Water used. Quantity.	Water used. Depth.	Area per cubic foot per second.[2]
	Acres.	*Acre-feet.*	*Feet.*	*Acres.*
April	1,108.5	272.9264	0.25	
May	1,108.5	1,331.2051	1.20	
June	1,108.5	2,060.0297	1.86	
July	1,108.5	1,552.0660	1.40	
August	1,108.5	420.4952	.38	
September	1,108.5	257.0571	.23	
Total irrigation		5,893.7795	5.32	63.01
Rainfall			.49	
Total water received			5.81	

[1] For the purpose of estimating depth of water used, the whole area is assumed to have been irrigated each month.
[2] Continuous flow for 169 days.

UPPER CANAL.

Under the Upper Canal about 300 acres is sandy, gravelly bench land, about 1,200 acres is clayey bench land, not requiring quite so much water as the gravelly bench land, and about 90 acres is bottom land, requiring still less water than the clayey bench land. The total area is 1,590.5 acres. The following table shows the daily use of water on these lands. The flow of the canal from April 20 to June 3 is estimated.

Water used in irrigating lands under the Upper Canal, 1899.

[See diagram, Pl. X, p. 74.]

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	71.4050	103.1402	104.9256	37.8843	23.2066
2		71.4050	105.1237	104.3306	39.6678	19.2397
3		71.4050	107.1072	108.7355	39.2727	18.2479
4		71.4050	116.6331	108.1405	47.2066	21.0248
5		71.4050	111.4711	102.5455	37.0909	19.2397
6		71.4050	107.1074	101.9504	36.4959	23.2066
7		71.4050	107.7025	101.3554	37.8843	24.3967
8		71.4050	108.4959	102.8471	37.4876	23.8017
9		71.4050	109.0909	106.0992	37.0909	23.2066
10		71.4050	109.8843	105.1240	36.4959	23.8017
11		71.4050	110.4793	108.0992	34.5124	21.6198
12		71.4050	111.2727	107.1074	34.1157	19.2397
13		71.4050	111.8678	107.1074	31.1405	18.2479
14		71.4050	112.6612	97.5868	26.7769	19.2397
15		71.4050	113.4545	96.5786	27.3719	18.8430
16		71.4050	114.0496	103.3388	26.7769	18.2479
17		71.4050	121.9835	85.6859	26.7769	19.2397
18		71.4050	101.3554	89.2562	24.9917	21.6198
19		71.4050	102.3471	89.2562	24.3967	19.2397
20	38.8700	71.4050	103.3388	85.6859	23.8017	18.8430
21	38.8700	71.4050	103.3388	84.6942	24.9917	19.2397
22	38.8700	71.4050	83.9008	83.9008	21.3967	18.8430
23	38.8700	71.4050	89.2562	84.6942	22.2149	19.2397
24	38.8700	71.4050	83.9008	79.3388	24.9917	18.8430
25	38.8700	71.4050	84.6942	68.2314	24.9917	17.6529
26	38.8700	71.4050	101.3554	60.0992	24.3967	18.2479
27	38.8700	71.4050	102.3471	60.0992	24.9917	17.6529
28	38.8700	71.4050	97.5868	47.6017	24.9917	18.2479
29	38.8700	71.4050	106.1157	47.2066	23.2066	18.8430
30	38.8700	71.4050	105.5207	44.2314	24.3967	18.2479
31	...	71.4050	....	40.6612	19.2397	....
Total	427.6900	2,213.5550	3,145.9027	2,710.2148	930.2480	598.8101

Duty of water under the Upper Canal, 1899.

Month.	Area.[1]	Water used		Area per cubic foot per second.[2]
		Quantity.	Depth.	
	Acres.	*Acre-feet.*	*Feet.*	*Acres.*
April	1,590.5	427.6900	0.27	....
May	1,590.5	2,213.5550	1.39	....
June	1,590.5	3,145.9027	1.98	....
July	1,590.5	2,710.2148	1.70	....
August	1,590.5	930.2480	.58	....
September	1,590.5	598.8101	.38	....
Total irrigation		10,026.4166	6.30	51.63
Rainfall		....	.49	....
Total water received		....	6.79	....

[1] For the purpose of computing the depth of water used, the whole area is assumed to have been irrigated each month.
[2] Continuous flow for 164 days.

GREEN DITCH.

The acreage under the Green Ditch is all bottom land. About 200 acres of it is gravelly land, requiring much water; the remainder is rich, loamy soil, requiring less water. The total area irrigated under this ditch is 586.25 acres. The daily use of water from this ditch is shown by the following table. The flow from April 20 to June 4 is estimated.

Water used in irrigating lands under the Green Ditch, 1899.

[See diagram, Pl. XIV, p. 74.]

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	16.4628	19.8347	17.0579	8.7273	12.4959
2	....	16.4628	19.8347	15.8678	6.1488	12.4959
3	....	16.4628	19.8347	14.4793	5.7521	12.0992
4	....	16.4628	19.8347	13.2893	6.1488	11.7025
5	....	16.4628	24.1983	11.9008	5.7521	12.0992
6	....	16.4628	23.0083	10.5124	5.5537	11.7025
7	....	16.4628	21.6198	9.1240	4.7603	10.7107
8	....	16.4628	22.6116	6.3471	15.8678	16.6612
9	....	16.4628	23.6033	9.5207	26.9752	17.8512
10	....	16.4628	24.5950	9.5207	26.1818	18.4463
11	....	16.4628	25.5868	3.7686	25.1901	18.4463
12	....	16.4628	26.5785	6.1488	24.7934	17.8512
13	....	16.4628	27.5702	6.3471	24.7934	17.8512
14	....	16.4628	28.5620	8.7273	24.1983	18.4463
15	....	16.4628	29.5537	6.1488	24.7934	18.4463
16	....	16.4628	33.9174	12.0992	23.8017	17.8512
17	....	16.4628	38.2810	8.7273	22.0165	17.4545
18	....	16.4628	42.4463	10.3140	21.0248	17.8512
19	....	16.4628	33.3213	10.7107	20.4298	17.8512
20	12.4562	16.4628	32.3306	7.1405	19.8347	16.6612
21	12.4562	16.4628	31.3388	6.1488	19.8347	15.4711
22	12.4562	16.4628	30.5455	6.1488	19.4380	14.2810
23	12.4562	16.4628	25.3884	6.3471	16.6612	14.2810
24	12.4562	16.4628	24.7934	6.3471	16.2645	13.8843
25	12.4562	16.4628	21.2231	6.1488	16.2645	12.8926
26	12.4562	16.4628	9.5207	3.7686	15.8678	12.8926
27	12.4562	16.4628	8.5289	3.5702	14.6777	13.0909
28	12.4562	16.4628	11.7025	10.7107	13.8843	13.8843
29	12.4562	16.4628	19.6364	9.1240	13.8843	13.8843
30	12.4562	16.4628	18.4462	9.1240	13.0909	14.2810
31	....	16.4628	....	8.7273	12.8926	....
Total	137.0182	510.3468	754.5116	273.9177	515.5045	453.8183

Duty of water under the Green Ditch, 1899.

Month.	Area.[1]	Water used.		Area per cubic foot per second.[2]
		Quantity.	Depth.	
	Acres.	*Acre-feet.*	*Feet.*	*Acres.*
April	586.25	137.0182	0.23	....
May	586.25	510.3468	.87	....
June	586.25	754.5116	1.30	....
July	586.25	273.9177	.47	....
August	586.25	515.5045	.88	....
September	586.25	453.8183	.77	....
Total irrigation	....	2,645.1171	4.52	71.97
Rainfall	....	....	.49	....
Total water received	....	....	5.01	....

[1] For the purpose of estimating the depth of water used, the whole area is assumed to have been irrigated each month.
[2] Continuous flow for 164 days.

LOWER CANAL.

The acreage under the Lower Canal is all bottom land. It is all good, rich soil except that which has become swampy by irrigation above. The pasture land is watered only once or twice during the irrigating season. A number of small springs, caused by seepage from higher irrigated lands, rise on this land, and serve to slightly increase the calculated duty, as they were not taken into account in the water measurements. There are 71 [illegible] ted from this canal. The

following table shows the flow of the canal from April 25 to September 20, when irrigation closed. The flow from April 25 to June 19 is estimated:

Water used in irrigating lands under the Lower Canal, 1899.

[See diagram, Pl. XI, p. 74.]

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	16.2645	21.9852	16.2645	16.2645	9.5207
2	....	16.2645	21.9852	15.8678	15.6694	6.3471
3	....	16.2645	21.9852	15.2727	15.6694	6.1487
4	....	16.2645	21.9852	14.6777	18.4463	3.5702
5	....	16.2645	21.9852	14.0826	16.6612	3.5702
6	....	16.2645	21.9852	13.4876	16.2645	3.3719
7	....	16.2645	21.9852	12.8926	18.4463	4.7603
8	....	16.2645	21.9852	13.6859	15.0744	3.5702
9	....	16.2645	21.9852	12.8926	11.9008	3.3719
10	....	16.2645	21.9852	12.4959	10.3140	3.5702
11	....	16.2645	21.9852	5.7521	9.5207	3.5702
12	....	16.2645	21.9852	6.1488	9.5207	3.3719
13	....	16.2645	21.9852	14.4793	10.3140	2.9752
14	....	16.2645	21.9852	12.4959	9.5207	4.5620
15	....	16.2645	21.9852	12.4959	6.3471	4.5620
16	....	16.2645	21.9852	14.4793	6.1487	3.5702
17	....	16.2645	21.9852	12.4959	6.3471	3.5702
18	....	16.2645	21.9852	13.8843	9.5207	3.5702
19	....	16.2645	21.9852	12.4959	9.1240	3.1736
20	....	16.2645	22.0165	12.8926	8.7273	2.9752
21	....	16.2645	20.4298	14.4793	7.5372	....
22	....	16.2645	20.4298	12.0992	4.7603	....
23	....	16.2645	14.8760	12.4959	4.5620	....
24	....	16.2645	25.5868	12.0992	5.5537	....
25	13.3289	16.2645	23.8017	12.0992	6.1487	....
26	13.3289	16.2645	20.4298	13.8843	8.5702	....
27	13.3289	16.2645	19.8347	12.4959	4.5620	....
28	13.3289	16.2645	18.1463	19.6364	4.7603	....
29	13.3289	16.2645	17.4545	19.8347	4.5620	....
30	13.3289	16.2645	16.8595	20.8264	6.9421	....
31	....	16.2645	....	15.4711	8.5289	....
Total	79.9734	504.1995	637.8842	424.6615	301.2892	83.7021

Duty of water under the Lower Canal, 1899.

Month.	Area.[1]	Water used. Quantity.	Water used. Depth.	Area per cubic foot per second.[2]
	Acres.	*Acre-feet.*	*Feet.*	*Acres.*
April	717.25	79.9734	0.11	....
May	717.25	504.1995	.70	....
June	717.25	637.8842	.89	....
July	717.25	424.6615	.59	....
August	717.25	301.2892	.42	....
September	717.25	83.7021	.12	....
Total irrigation	....	2,031.7099	2.83	104.43
Rainfall	....	....	.49	....
Total water received	....	....	3.32	....

[1] For the purpose of estimating the depth of water used, the whole area is assumed to have been irrigated each month.
[2] Continuous flow for 149 days.

BIG DITCH.

The acreage under the Big Ditch is all bottom land except about 250 acres of sandy bench land near the Jordan River. It is all good, rich soil except the pasture, which is wet land, requiring only one or two

waterings during the irrigating season. A number of springs also rise on this land and serve to slightly increase the calculated duty, as in the case of the Lower Canal. The total area irrigated from this ditch is 2,243.13 acres.

The daily flow of the Big Ditch is given in the following table. The flow from April 25 to June 6 is estimated:

Water used in irrigating lands under the Big Ditch, 1899.

[See diagram, Pl. XV, p. 74.]

Day.	April.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	53.2562	55.5372	65.8512	40.6612	23.8017
2	....	53.2562	55.5372	65.0578	39.8678	23.2066
3	....	53.2562	55.5372	64.2645	37.8843	18.8430
4	....	53.2562	55.5372	63.4711	52.3636	18.2479
5	....	53.2562	55.5372	62.6777	51.5702	17.6529
6	....	53.2562	45.6198	62.0826	50.7769	16.0661
7	....	53.2562	54.5455	61.6859	50.7769	14.0826
8	....	53.2562	63.6694	59.3058	40.8595	14.0826
9	....	53.2562	72.5950	78.5455	31.1405	16.0661
10	....	53.2562	81.5207	60.0992	30.5455	15.6694
11	....	53.2562	80.7273	50.7769	23.8017	16.0661
12	....	53.2562	79.9339	55.3388	24.9917	15.6694
13	....	53.2562	79.1405	55.3388	27.3719	14.0826
14	....	53.2562	78.3471	54.7438	26.7769	15.6694
15	....	53.2562	77.3554	76.7603	24.3967	16.0661
16	....	53.2562	76.5620	88.2645	21.6198	15.0744
17	....	53.2562	75.7686	68.2314	21.0248	14.0826
18	....	53.2562	74.9752	60.0992	27.3719	16.0661
19	....	53.2562	74.1818	51.5702	26.7769	15.6694
20	....	53.2562	75.9669	50.7769	24.3967	15.6694
21	....	53.2562	75.9669	52.3636	21.6198	....
22	....	53.2562	70.8099	43.4380	13.6859	....
23	....	53.2562	65.8512	44.2314	13.6859	....
24	....	53.2562	77.7521	43.4380	13.6859	....
25	45.4807	53.2562	78.5455	26.7769	19.2397	....
26	45.4807	53.2562	78.5455	31.1405	14.0826	....
27	45.4807	53.2562	79.3388	31.1405	13.6859	....
28	45.4807	53.2562	67.4380	54.7438	14.0826	....
29	45.4807	53.2562	67.4380	52.3636	19.2397	....
30	45.4807	53.2562	66.6446	51.5702	18.8430	....
31	....	53.2562	....	36.4959	24.3967	....
Total	272.8842	1,650.9422	2,096.9256	1,722.6445	861.2231	331.8344

Duty of water under the Big Ditch, 1899.

Month.	Area.[1]	Water used.		Area per cubic foot per second.[2]
		Quantity.	Depth.	
	Acres.	*Acre-feet.*	*Feet.*	*Acres.*
April	2,243.13	272.8842	0.12	....
May	2,243.13	1,650.9422	.74	....
June	2,243.13	2,096.9256	.93	....
July	2,243.13	1,722.6445	.77	....
August	2,243.13	861.2231	.38	....
September	2,243.13	331.8344	.15	....
Total irrigation	....	6,936.4540	3.09	95.64
Rainfall	....	....	.49	....
Total water received	....	....	3.58	....

[1] For the purpose of estimating the depth of water used the whole area is assumed to have been irrigated each month.
[2] Continuous flow for 149 days.

where water is diverted, and proceed upstream, measuring the width and depth of water flowing at the head of each canal as they go. In this way the number of "square inches" flowing into each canal is obtained. These are added together to obtain the total number of "square inches" diverted. Then the water masters usually proceed downstream, regulating the quantities of water diverted, so that each canal will have its proper number of "square inches," according to the shares allotted by the arbitration, although this rule is not always closely followed. This regulation of the water holds good until another division is called for. They realize that there is nothing accurate about this method of measurement, but have always made it in that way. The measurement was usually made over a board at the head of the canal. This year it was made over Cippoletti weirs (Pl. XLVII). A stream 100 inches wide and 5 inches deep would be 500 "inches," according to their method, and a stream 50 inches wide and 10 inches deep would also be 500 "inches." No allowance is made for differences in velocity in the various canals. The upper ditches take out their full number of "inches," and the lower ditches take what they can get.

The division of the water among the owners of any ditch is made by the water master. A description of the ownership and method of dividing the water on the Brown & Sanford Ditch will serve as an illustration.

Ownership in the water goes by shares or "rods," each rod representing that length of the main ditch built by the first owners. The water master kept track of the construction work, calculated the acreage to which different ones were entitled according to such work, and made out certificates for the same. Usually the farmers do not form a regular company, but simply club together and furnish labor for the construction of the main ditch. Water enters all the main branches by self-dividing gates, the widths being proportioned to the shares, no attempt being made to attain accuracy. During low water these branches usually take turn about in carrying the full flow allowed to the main ditch, as the water will go much farther by thus using a large head.

For the individual owners on each main branch there is an allotment to each of the full flow for a certain number of hours, beginning at the one nearest the head and following down in regular order. Usually seven and one-half days or one hundred and eighty hours is the period for one rotation, the watering then beginning at the head again. Each owner's gate is fixed so that he can take the full flow, and his water ticket shows the date and number of hours he is entitled to all of the water, so that he can at once divert it when his time begins, at which time the one above is to cease diverting it. Where there is harmony among the owners, all this is done without need of superintendence on the part of the water master, his main work being in making out the

tickets of time for such distribution. The "rods" or shares are sometimes divided into quarters, and even smaller fractions, to suit the various holdings.

From what has been said it will be noted that it would not be easy to obtain a legally defined title to water on this stream, and that it would be impossible to determine how much water any given right represents.

STUDIES OF DUTY OF WATER IN 1899.

Instructions to measure the water diverted from Big Cottonwood Creek by canals and ditches were not received until about June 1, 1899. As soon as possible thereafter, Cippoletti trapezoidal weirs were put in the canals and ditches at points near the headgates, and the measurements were begun. It required considerable persuasion in some instances to obtain permission to put in the weirs. There has been more or less friction among the owners of the various canals and ditches, and some of them did not want the water measured at all. The owners of the Tanner Ditch would not allow a weir to be put in where all of the water they diverted could be measured. During part of the season they ran water from the creek through a small branch, turning it into their ditch at a point about 50 yards below the weir. At the time the weir was put in owners of other ditches said they would shut off this branch, claiming that the Tanner Ditch had no right to take water through it; but this was not done until the creek had fallen to low-water stage. The measurements made in the Tanner Ditch are, therefore, of little or no value. The weir on the Farr & Harper Ditch was torn out by the ditch owners after being in only one day, and arrangements were not completed for replacing it until early in July. Most of the water measured in the Walker Ditch was merely run through a fish pond, only a small portion of it being used for irrigating purposes.

The heads on the weirs were measured once a day with a hook gage. Probably the heads should have been measured at least twice a day, as there is generally a slight variation between morning and evening in the discharge of the creek. But as the weir measurements were made at all hours of the day, and not at any particular time for each ditch, it is believed that a fair average of the flow was obtained.

In order to calculate the duty of water it has been necessary to estimate the flow in the canals and ditches during April, May, and the early part of June. In doing this use has been made of gagings of the discharge of the creek. These gagings were made by Mr. F. C. Kelsey, city engineer of Salt Lake City, over a Cippoletti weir, the head being measured twice a day with a hook gage. The estimates of flow in canals and ditches during that part of the irrigating season when weir measurements were not taken have been thoughtfully and

carefully made, and it is believed that they are pretty close to the truth. For reasons previously stated, no attempt has been made to calculate the duty of water under the Tanner, Farr & Harper, or Walker ditches.

The irrigating season usually begins about April 15 and ends about September 30. The date when irrigating is begun varies with the seasons; with a dry spring it may begin as early as April 1, and with a wet spring it may begin as late as May 1.

During the winter of 1898–99 there was an unusually heavy snowfall in the mountains on the drainage area tributary to this creek. For this reason there was an abundance of water for all ditches during the early part of the irrigating season, and it is believed that more water was taken out then than was needed, and that the duty of water was therefore lower than usual.

The following table shows the precipitation as recorded by the Weather Bureau at Salt Lake City:

Precipitation at Salt Lake City, Utah, October, 1898, to September, 1899.

Month.	Rainfall.	Above normal.	Below normal.
1898.	*Inches.*	*Inches.*	*Inches.*
October	1.57	0.03	
November	1.95	.59	
December	1.28		0.36
1899.			
January	.84		.60
February	2.98	1.70	
March	2.93	.90	
April	.81		1.40
May	2.59	.87	
June	.96	.17	
July	.42		.11
August	1.06	.34	
September			.23
Total	17.39	4.60	2.70

From the above table it will be noted that the precipitation from October, 1898, to March, 1899, inclusive, was 2.26 inches in excess of the normal; while during the irrigating season, from April to September, 1899, inclusive, it was 0.36 inch below the normal.

In order to make an intelligent comparison of the duty of water under the various canals it is necessary to know what kinds of lands were irrigated in each case. As a general statement it may be said that bench land requires about 50 per cent more water than bottom land.

BUTLER DITCH.

The acreage irrigated by the Butler Ditch is all sandy, gravelly bench land, requiring much water. The area irrigated under this ditch is 123.5 acres. The following table shows the daily use of water on lands under this ditch from April 15, when irrigation began, to

and the ditches were supposed to have certain bottom widths. As a matter of fact, however, the cross section and grade of any given ditch varies between rather wide limits, as may readily be imagined from the methods of construction.

HISTORY OF ARBITRATION.

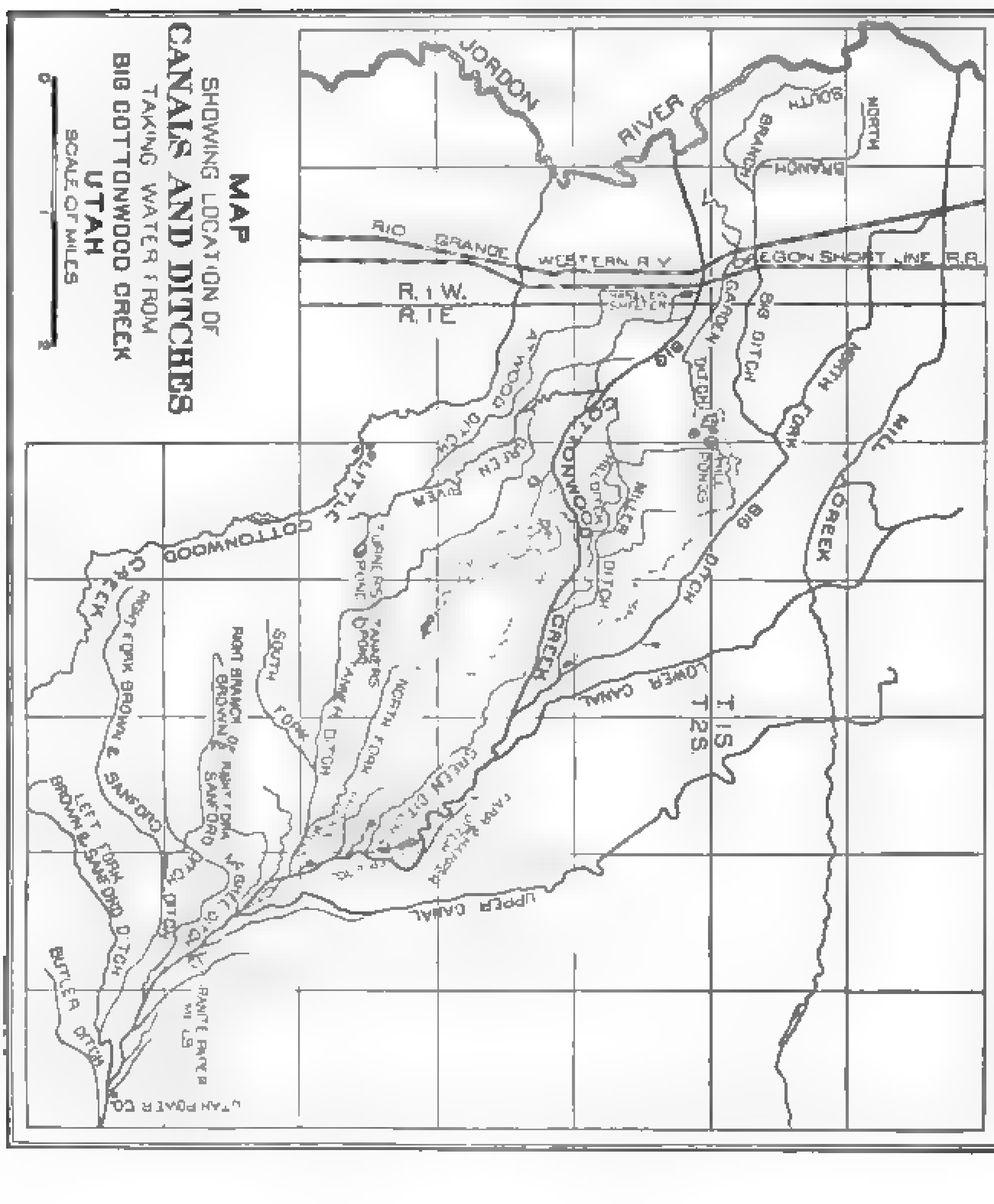
On September 13, 1879, the district court of the Territory of Utah appointed Joseph S. Rawlins, Reuben Miller, and D. B. Brinton, after they had previously been chosen by the water owners of Big Cottonwood Creek, a board of arbitrators to adjust all claims to the water of said creek and report its findings to said district court. This board, for convenience, divided the creek into 60 parts. One part would entitle its owner to irrigate 127.25 acres during time of low water. Each part, or share, was taken to mean one-sixtieth of the waters flowing in the creek at the highest point thereon where water is diverted by any of the canals or ditches mentioned in said agreement for arbitration. Only those holding primary rights were allotted shares during low-water season. The board classified the different canals and ditches, and parts, or shares, were allotted as follows:

Division of the water of Big Cottonwood Creek.

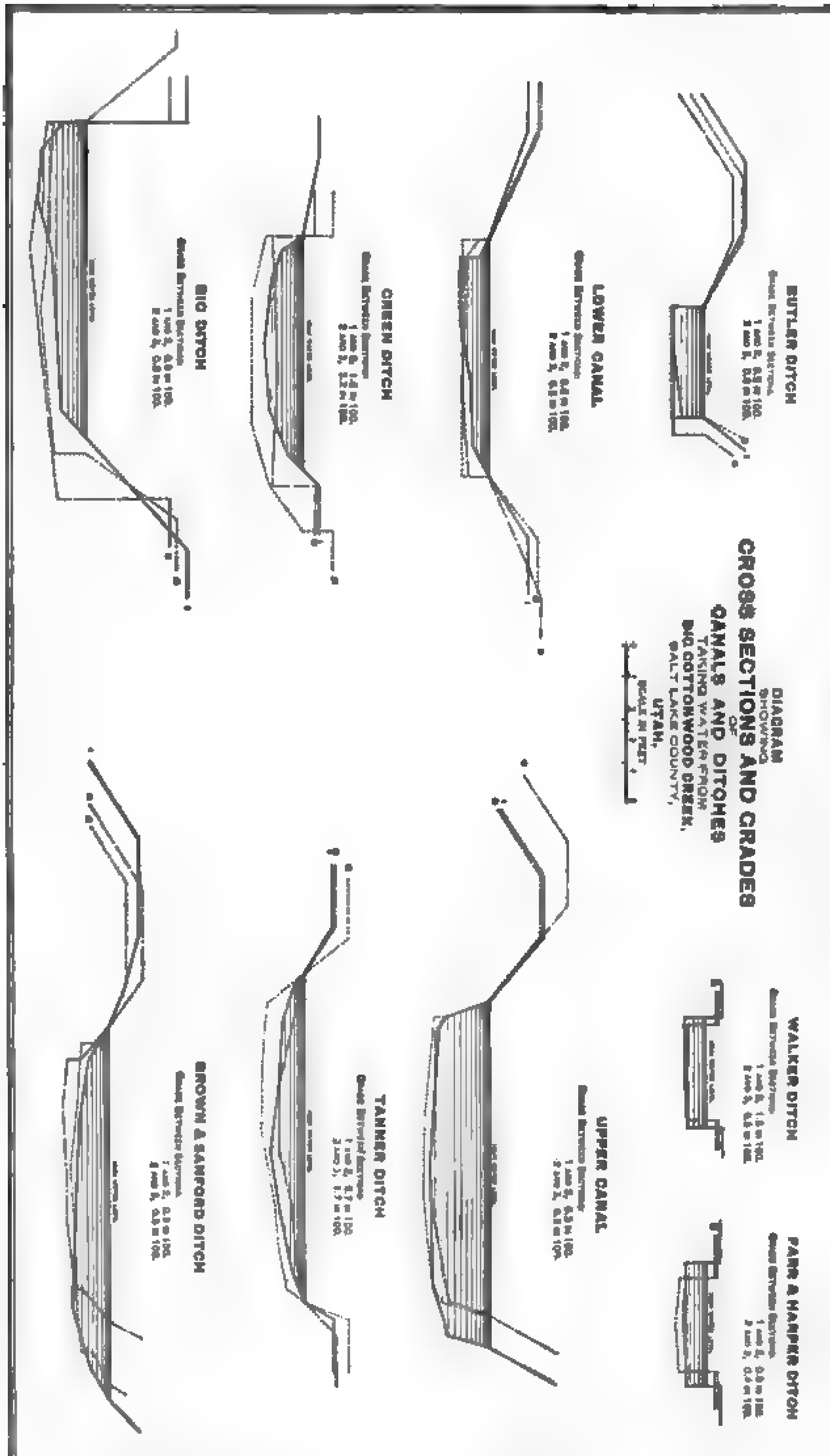
Class.	Name of ditch.	Number of parts.	
		January 1 to July 1.	July 1 to January 1.
1	Butler Ditch	0.5	0.2
2	Brown & Sanford Ditch	4.5	2.1
3	Upper Canal	10.5	10.2
4	Tanner Ditch	12.6	12.9
5	Green Ditch	3.5	3.8
6	Farr & Harper Ditch	.6	.6
7	Lower Canal	5.6	6.1
8	Big Ditch	19.6	21.3
9	Hill Ditch	2.6	2.8
	Total	60.0	60.0

A formal printed report showing the results of the action of the board of arbitration was made to the district court, and was properly filed. Each owner of a primary right in the stream was served with a written or printed notice of the arbitration, and a time was set by the court for hearing objections to said arbitration. No one appeared or objected, and the judgment of the court was rendered in accordance with the terms of the arbitration.

Nearly all of the owners of primary water rights appeared before the board of arbitrators and signed, under oath, an agreement to accept the division made by the board as binding and final. This agreement was properly filed with the district court, but has since disappeared and can not now be found. There were a few who did not sign this agreement, notably the Walker Brothers and a few owners on the Green Ditch. Others now claim that they did not sign the agreement,



Map Showing the Location of Canals and Ditches Taking Water from Big Cottonwood Creek, Utah.



CROSS SECTIONS OF CANALS TAKING WATER FROM BIG COTTONWOOD CREEK, UTAH.

Rainfall and evaporation[1] at Logan, Utah, 1899.

Day	June. Rain.	June. Evaporation.	July. Rain.	July. Evaporation.	August. Rain.	August. Evaporation.	September. Rain.	September. Evaporation.
	Inch.	*Inches.*	*Inch.*	*Inches.*	*Inch.*	*Inches.*	*Inch.*	*Inches.*
1	0.18			0.35				
2		0.50					0.02	0.52
3								
4					0.38			
5	.42				.18	1.48		
6								
7					.10			
8				2.02				
9					.04			1.83
10		1.68						
11			0.47					
12						1.88		
13								
14								
15			.05	1.78				
16								1.82
17		1.61						
18								
19						2.04		
20								
21								
22				2.22				
23								1.62
24		2.09						
25								
26			.03			2.06		
27			.05					
28								
29				2.30				
30		2.11						1.26
31				.90		1.32		
Total	.60	7.99	.60	9.57	.70	8.77	.02	7.05

[1] Evaporation is for the week ending on the date for which it is given.

The observed duty of water under the Logan and Richmond Canal is given in the following table:

Duty of water under the Logan and Richmond Canal, 1899.

Month.	Area irrigated	Total discharge	Depth of irrigation.	Average daily discharge.		Area irrigated from each cubic foot per second.
	Acres.	*Acre-feet.*	*Feet.*	*Acre-feet.*	*Sec.-feet.*	*Acres.*
June	2,894	2,652.2257	0.9165	88.4075	44.5721	64.93
July	2,894	3,784.4008	1.3077	122.0774	61.5474	47.02
August	2,894	2,126.0856	.7348	68.6080	34.5873	83.67
September (26 days)	2,894	1,821.9277	.6296	70.0741	35.3290	81.92
Season (118 days)	2,894	10,385.2498	3.5885	88.0106	44.3720	65.22

Summary.

Area irrigated	acres..	2,894
Water used	acre-feet..	10,385.2498
Depth of irrigation	feet..	3.59
Depth of rainfall	do...	.16
Total depth of water received by land	do...	3.75

By referring to the table on page 214, it will be seen that 1,366 acres was irrigated less than three times, and that 1,528 acres was irrigated three or more times. The average number of irrigations was slightly more than three, and the average depth supplied at each irrigation 1.2 feet.

The demand for water was greatest during June and July. This was due to the fact that both alfalfa and wheat are irrigated during these months. The need in July was greater than in June, while the demand in August and September was largely owing to the irrigation of alfalfa. During the latter part of September much water ran to waste; hence the requirements for that month were less than the volume measured. An average flow of 44.37 cubic feet per second during the four principal irrigation months irrigated 2,894 acres, or a duty of 65.22 acres for each cubic foot per second.

This result includes losses from seepage and evaporation in the canal.

Alfalfa and wheat are grown on nearly three-fourths of the area irrigated; hence the result applies especially to those two crops. The lands irrigated were of nearly every quality except alkali lands; therefore the result obtained represents a fair average for the lands in this vicinity.

DUTY OF WATER ON THE CRONQUIST FARM.

The measurements of the water flowing through the main canal gave a duty which included the loss in distribution. In order to estimate, if possible, the influence of this loss, a measurement was made of the water actually applied to a definite tract, the location selected being a 60-acre farm situated near the heart of the irrigation district and irrigated from the canal. This was watered from two laterals, one entering the farm at the northeast and the other at the southeast corner. A Cippoletti weir was placed at the corner of the field where the main lateral entered, and one of the automatic recorders of the Department was arranged to record the depth of water passing over it. In one other supplying lateral, a small rectangular flume was placed, and during irrigation the depth of water was read at least three times a day, and the velocity at each observed depth was determined. By these means an accurate measurement of all water used was obtained. Whenever irrigation was in progress, daily visits were made to the farm and a record was kept of the progress made. The date and duration of each irrigation and the kinds of crops and acres devoted to each were noted. The orchard referred to in the following table is young, with a garden between the rows of trees, so that the irrigation of the two is necessarily considered together.

Irrigation of Cronquist farm, season of 1899.

[See diagram, Pl. XVII, p. 76.]

Crop.	Acres.	Date of irrigation.	Hours.	Acre-feet.	Depth.	Total depth.[1]	Method of distribution.	Cash value of product.
					Feet.	*Feet.*		
Wheat	15	June 19–22	50.08	14.64	0.97	0.97	Flooding	$162
Do	4	July 13, 14	18.00	3.76	.94	.94	....do....	43
Alfalfa	20	July 9–15	145.00	47.40	2.37	3.83	....do....	500
		August 17–22	110.00	29.20	1.46			
Do	2	July 11	18.00	2.68	1.34	3.19	....do....	50
		August 20	18.00	3.70	1.85			
Orchard and garden	1.5	June 20	16.00	2.10	1.40	5.95	Furrow	[2]200
		July 15	24.00	2.90	1.93			
		August 16	14.00	1.95	1.30			
		September 20	15.00	1.98	1.32			
Total	42.5		437.08	110.31				950

[1] Add 0.16 foot rainfall for total depth of water received by the land.
[2] Estimated.

In common with the usual practice, the water wasted over the lower side of the field was a large percentage of what was supplied at the upper. This, rather than the need of the crop, caused the application of enough water to cover the alfalfa to a depth of 3.77 feet and the 1.5 acres of garden to a depth of 5.95 feet.

The alfalfa produced three crops and averaged during the season 5 tons to the acre, or a total of 110 tons. The wheat crop was considerably below the average, but gave a return of 27 bushels to the acre, or a total of 513 bushels. The orchard and garden comprised a variety of products, among them 125 bushels of potatoes, a large quantity of fruit, and the ordinary garden products, besides a small amount of sugar cane. An estimate of the cash value of the products at the present market price gives a return from the 42.5 acres of $950.

The table shows that enough water was used to cover the 42.5 acres irrigated to a depth of 2.59 feet. The water flowing in the main canal was sufficient to cover the land irrigated to a depth of 3.59 feet. This indicates a loss of 28 per cent of the water flowing in the canal, assuming that the Cronquist farm fairly represents the farms under the canal.

IDAHO.

DUTY OF WATER AS RELATED TO THE IRRIGATION PROBLEMS OF THE BOISE VALLEY, IDAHO.

By Special Agent D. W. Ross,
State Engineer of Idaho.

BOISE VALLEY.

The total area of irrigable land in the Boise Valley is five times greater than the area now watered. The problem which confronts us is to so increase the duty of water that the entire area may be irrigated and become productive.

The Boise Valley (Map, Plate XLIX) might easily be regarded as a part of the great sagebrush plains of the Snake River, simply a widening out of that monotonous stretch of desert land which begins within sight of the Yellowstone National Park and extends westward without break for a distance of nearly 600 miles. There is the same great sweep of undulating bench land, the same gray ashy soil that filters through the closed double windows of the Pullman as it speeds through southern Idaho. To the eye of the topographer, however, one difference presents itself—the Boise River, running between low banks, may be easily diverted. The barriers left by nature are slight, and at reasonable expense its waters are transforming this once desert waste into a fit habitation for man.

The irrigable portion of the Boise Valley lies at an elevation of from 2,400 to 2,800 feet above sea level. On the north side of the river, beyond the valley proper, gently sloping terraces rise one above the other and merge gradually into the foothills. On the south a somewhat similar system of terraces, though much broader, ends finally in a broken ridge parallel to and about 3 miles distant from Snake River. Natural drainage courses run from east to west through this portion of the valley, emptying into the river near Caldwell. These were originally dry except during the spring freshets. They cause only slight undulations in the surface of the ground and now serve as distributary channels and waste ways in the irrigation system.

There are nearly 634 square miles of land lying under the canals and ditches already constructed or projected, and of this 484 square miles, or 310,000 acres, are susceptible of irrigation. About 40,000 acres is known as the first bottom or valley proper, which lies from 5 to 15 feet above the river. The bench lands rise to a height of nearly 125 feet above the river near the lower end of the valley.

WATER SUPPLY.

Rainfall.—The United States Weather Bureau reports an average rainfall for the year at Boise of nearly 14 inches. At Nampa, the center of the irrigable portion of the valley, it is but half that amount. Of this an average of 3.5 inches falls during the irrigation season and less than 1 inch falls during the hot months of June, July, and August. Thus it may be plainly seen that unless moisture is artificially applied to the soil, the country must always remain in a desert condition.

Boise River.—The Boise River rises in the Saw Tooth Mountains. The area of its drainage basin, which lies at an elevation of from 4,000 to 9,000 feet above the sea, is about 2,450 square miles. The greater portion of this is well timbered, and in the high elevations where this growth is plentiful the snow lies until well into June and July. In the lower elevations and foothills, or where there is but a sparse growth of timber, the snow disappears under normal conditions during the month of May; hence the flood-water season begins during that month, reaching its highest mark during the month of June, and lasts until near the middle of July.

Like all mountain streams whose chief source of supply is the melting snow, the Boise River quickly subsides after its highest stage is reached, and the period of low water soon follows.

The mountain portion of the river channel has a fall of from 25 to 200 feet per mile, while from the Boise Canyon to its mouth, a distance of about 60 miles, its total fall is 600 feet, or an average fall of 10 feet per mile. After emerging from between the high walls of the Boise Canyon the stream winds about between low banks, seldom confined during high water to one channel. At one point in its course through the valley the high bench lands on both sides are joined by a lava dike through which the water has cut the Caldwell Canyon.

The diagram (fig. 18, p. 221) shows the discharge of the Boise River in acre-feet during the irrigating season from 1895 to 1899 inclusive.

This diagram discloses the fact that the low-water season of this period was in 1898, when, during the months of July, August, and September, the mean daily flow of the river was 1,917, 794, and 729 cubic feet per second, respectively. The greatest discharge of the river for any month during this period occurred in June, 1896, when the average daily flow was 22,112 cubic feet per second, the average discharge each day being more than one-third of the discharge during the entire month of July, 1898, or a quantity nearly equal to the total discharge during the month of August of that year. The high-water year for the irrigator, however, is the one during which the flood discharge is prolonged late into the irrigating season. This occurred during the year 1899. While the mean daily flow of the river during the month of June, 1899, was about one-half that during the same month in 1896, its average daily flow during the months of July, August, and September was greater than during the same months of 1896, the usual rush of

flood water having been checked by cool weather until late in the month of July. The diagram also indicates that a flood discharge of 40,000 cubic feet per second occurred in June, 1896. A subsidence to a flow of 2,000 cubic feet per second usually takes place during the

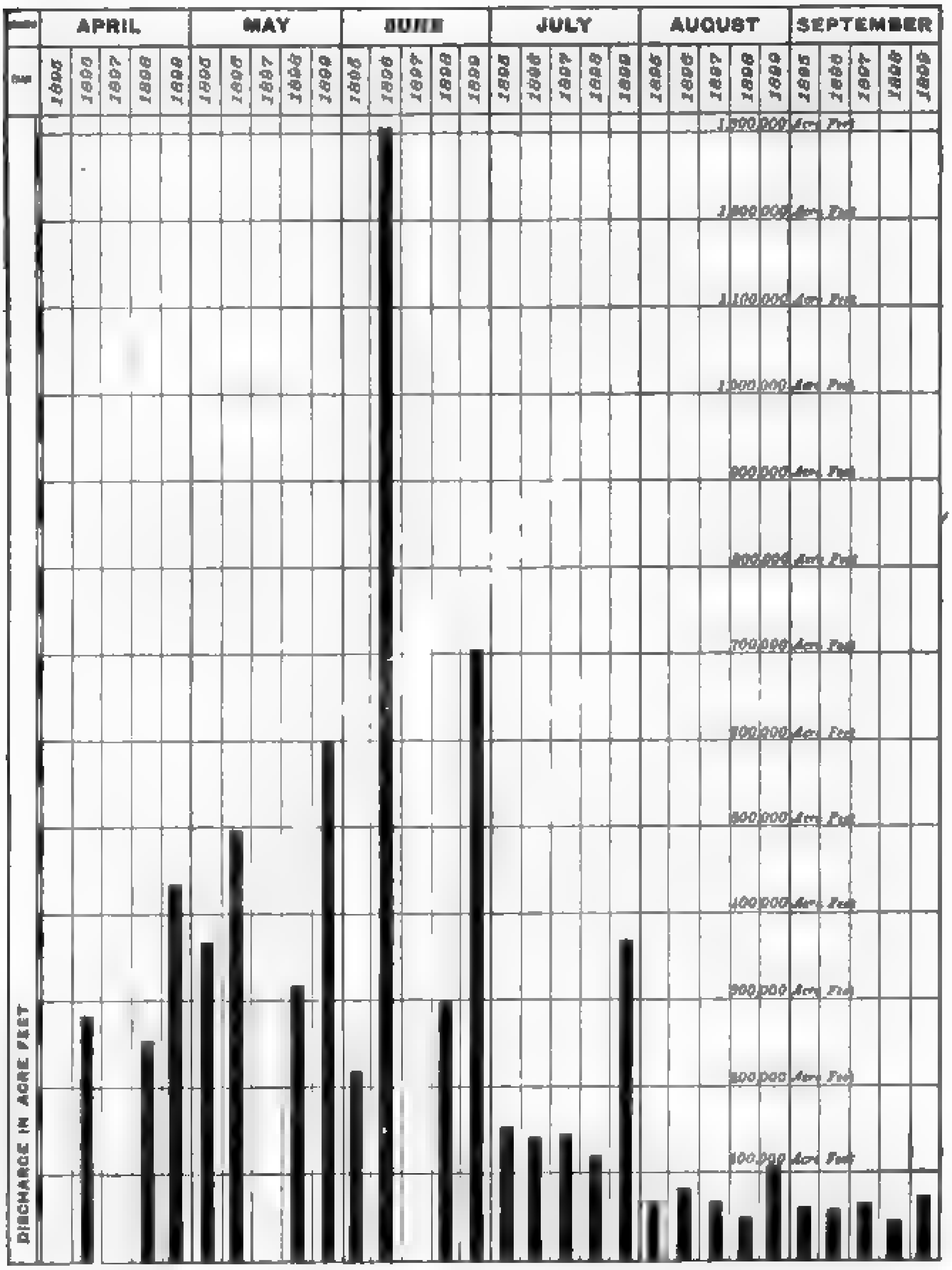


FIG. 18.—Diagram showing the discharge of the Boise River in acre-feet from 1895 to 1899, inclusive.

last week of July of each year. The average daily discharge during the months of August and September of the years from 1895 to 1899, inclusive, was 1,197 and 967 cubic feet per second, respectively, yet a greater volume than this is diverted from the river each day during these months and used for irrigation.

IRRIGATION INVESTIGATIONS IN THE BOISE VALLEY IN 1899.

AMOUNT OF WATER CLAIMED AND THE AMOUNT ACTUALLY DIVERTED.

In order that the investigation should embrace all of the factors which influence the duty of water in irrigation now obtained in this valley, it was thought desirable to secure a record of the claims to water from the stream and make such measurements as would show the location and capacity of the canals already built. Mr. Wiley, a civil engineer of Boise, Idaho, was employed to do this work. His reports give the abstract of the claims to water from the three counties through which the river flows. The abstracts of the records are omitted from this report because of the space they would occupy, and because of the fact that the claims of one county aggregate more than one hundred and sixty times the midsummer flow of the river. It would seem that the validity of such records would not be a matter of much practical importance.

Following the study of the water-right records, Mr. Wiley made surveys and gagings of the various canal systems. These canals now serve to irrigate about 50,000 acres of land, and have a total capacity of 1,741 cubic feet per second, and an estimated average discharge during the height of the irrigation season of 1,400 cubic feet per second. The results of Mr. Wiley's measurements are given in the following table. The diagram which follows the table shows graphically the difference between the amounts of water claimed by the several canals and the volumes they were actually diverting when measured.

Measurements of canals diverting water from the Boise River.

[Made by A. J. Wiley, June 25 to 30, 1899. See diagram, Pl. XLIX, p. 220.]

Name of canal.	Surface width.	Bottom width.	Average depth.	Discharge.
South side of river:	*Feet.*	*Feet.*	*Feet.*	*Cu. ft. per sec.*
Costons	9.0	6.0	0.87	7.536
Ridenbaugh	38.0	32.5	4.64	390.656
Payne	6.0	6.0	1.30	9.703
Rossi	16.0	16.0	2.50	52.930
Rossi waste	11.2	11.2	1.67	47.184
Lemp or Settlers	22.0	19.0	2.47	92.342
Davis	7.6	7.6	2.55	22.101
Catlin & Hart	5.3	5.3	0.94	4.667
Phyllis	18.0	12.0	2.96	85.996
Eureka	15.5	15.0	2.13	68.442
Caldwell (Strahorn)	13.0	10.0	2.44	74.972
Riverside	15.0	13.0	1.55	46.918
Keller	9.0	7.0	1.26	12.588
American	10.0	7.5	1.86	30.476
North side of river:				
Perrault (Walling)	9.3	6.0	1.86	23.333
Grove Street	8.5	7.0	1.52	14.796
Jacobs	11.6	10.0	2.42	46.443
Farmers' Union	26.6	21.0	2.07	94.994
Boise Valley	10.3	8.0	2.14	39.592
Dry Creek	18.0	12.0	2.47	53.199
Union	8.0	5.0	1.01	8.456
Ballentine	7.2	5.5	1.62	20.033
Cassiday	7.3	7.3	0.79	8.639
Middleton	18.0	14.0	3.58	141.979
Middleton Mill Slough	18.0	14.0	3.45	128.464
Swalley & McDowell	10.0	7.0	1.62	23.797
Middleton Water Company	22.0	20.0	1.87	81.104
Sebree	31.0	22.0	3.19	164.905
Total				1,741.207

Desert areas still exist in the Boise Valley. Irrigators are in constant strife over the division of water, yet the volume flowing in the river must serve to irrigate an area five times as great as that now under cultivation. One cause for this condition of affairs is that our plans in the beginning were too selfish and narrow. Each promoter thought only of his own scheme. He ignored entirely the efforts put forth at the same time by others similarly situated, and too often he introduced methods which were directly opposed to the general good. It has been left to his successor to save from ruin the enterprises sustained by the money of the capitalist and labor of the farmer; to bridge the gulf created between canal management and water users, and to show the necessity for the cooperation of every one from the landowner and land cultivator to the banker.

The extent to which the desert may be redeemed is measured by the amount of water at hand and the methods employed in its application. Therefore the policy pursued in the management of canals and the practice of the individual irrigator are the important factors in the problem of development and will, for that reason, be considered as part of the study of the duty of water.

DESCRIPTION OF THE PRINCIPAL CANAL SYSTEMS.

Boise and Nampa or Ridenbaugh Canal.—This canal, the highest and most important one in the Boise Valley, diverts its water supply from the south side of the Boise River at a point about 6 miles above Boise, and after crossing the first bottom of the river skirts the bluff and reaches the top of the first "bench" at a distance of about 8 miles from its head. From this point its course diverges rapidly from the river, being nearly 12 miles distant at a point south of Nampa. Four hundred and fifty feet below the headgate the canal is 38 feet wide at the surface of the water, 32.5 feet wide on the bottom, and 4.6 feet in depth, and diverts 390.6 cubic feet per second of water or 19,500 miner's inches, measured under a 4-inch pressure. Water is furnished for power for the Electric Light Company of Boise, being discharged just above the headgate of the Settlers' Canal. From 18 to 35 cubic feet per second are used for power purposes.

In order to avoid expensive construction on sidehill and broken ground, several vertical drops were introduced in the grade of the main canal, the land left on the upper side to be watered by means of laterals taken out above the drops and continued on the higher ground on the upper grade plane of the main canal. The accompanying map shows the system of upper laterals (Pl. XLIX, p. 220). Owing to the dropping of the ridge line between the Snake and Boise rivers, these upper laterals finally reached the level of the main canal at a point south of Nampa. By this location of the main canal a great saving was effected

in the cost of its construction, and owing to the topographical condition all the land which lies below the upper level of its grade plane may still be watered.

The management of this property, fully realizing the necessity of providing against the time of great demands by the irrigator and shortage of water in the river, is providing a storage system as shown on the maps. Sites have been selected for seven reservoirs along the line of the main canal which will have a combined storage capacity of 26,000 acre-feet or enough water to give 50,000 acres one thorough irrigation, allowing for all loss in the lateral system. By this means it will be possible for the large district which will ultimately be served by this system to tide over the low-water period in the Boise River. The plans of the company contemplate the early enlargement of its main canal to keep the reservoirs filled until they are needed. They will be filled each season during the month of June.

Until 1899 this company charged for the delivery of water by the acre, and the duty has been low—about 47 acres for every cubic foot per second flowing in the main canal below the electric power plant. The loss from seepage and evaporation in the canal has never been determined, but owing to the length it must be very great.

Perrault Ditch.—The ditch heads on the north side of the Boise River about 3 miles above Boise. The first 2 miles is used for floating logs and for power purposes. The irrigation ditch proper begins at the lower end of the log pond below Goodwin's sawmill, where a small head of water—less than 25 feet—is diverted and used for the irrigation of lots in Boise and a few farms lying near the city. The portion of this ditch used for irrigation is 9.3 feet wide at water surface, 6 feet wide on the bottom, and 1.9 feet deep, and when measured on June 30, 1899, it carried 23.3 cubic feet per second. All portions of this ditch which were expensive to construct and maintain are embraced within the upper 2 miles. The remainder, about 3 miles, is maintained at but little cost.

The annual charge for water for farm irrigation is $4 per acre, and it is delivered for the irrigation of lots at the rate of $7.50 per 50-foot lot. Water is supplied to the city for flushing sewers at a cost of about $1,800 per annum. There has been considerable litigation over rates charged for the delivery of water from the ditch, which has resulted in a court decision that the rate of $4 per acre to be paid annually is just and reasonable. About 800 acres, including city lots, is watered from this ditch.

Settlers' or Lemp Ditch.—This ditch diverts water from the Boise River west of Boise. It is 22 feet wide at the water surface, 19 feet wide on the bottom, and 2.5 feet deep, and carried on June 28, 1899, 92.3 cubic feet per second. About 4 miles from the headgate it reaches the top of the first bench, where it turns to the south nearly at right

angles to the course of the river and ends at the South Slough, 7 miles from the head. The owner of this canal charges by the acre for the delivery of water. The price paid is $1.50 per acre per year. No measuring boxes are provided, and the water users are forced to practice a system of rotation. Four thousand nine hundred and seventy acres were irrigated during the season of 1899, requiring a flow in the canal of over 92 cubic feet per second, or at the rate of 1 cubic foot per second for each 54 acres. The loss of water through seepage and evaporation is slight.

This canal was originally built by a company composed of the farmers whose lands are now watered by it, but owing to bad management the company became involved in debt and lost the property through foreclosure. The present owner then enlarged it to its present size, and is now deriving a handsome revenue on his outlay.

During the year 1896 the owners of the land lying below the level of this canal organized an irrigation district, for the purpose of purchasing and enlarging the canal to a capacity sufficient to water 21,000 acres of land. So favorable is the location, and so cheap would be the construction of the ditch that the plan had great merit, for by this arrangement the cost of water to irrigators might have been reduced to about one-third the present charge. For some unaccountable reason the plan has been abandoned.

Farmers' Union Ditch.—This canal is a community project, planned and built by farmers. It heads on the north side of the river about 2 miles below Boise, and will ultimately water all the land lying between the foothills and the first bottom of the river, a district about 12 miles long and of an average width of 1 mile. It is 26.6 feet wide at the water surface, 21 feet wide on the bottom, and 2 feet deep at a point 500 feet below the headgate. On June 21, 1899, it carried 95 cubic feet per second, and waters at present about 3,000 acres.

This company is organized under the corporation laws of the State, and has issued to its members shares of stock which entitle the owner to a certain amount of water. Both cash and labor assessments are levied to meet the expenses of operation. The stock held by each farmer represents a certain proportional interest in all rights and liabilities of the company, but from the nature of the enterprise there are no dividends, water being delivered at actual cost. In the absence of any law regulating the distribution of water from canals, the interest of each user presupposes a continuous flow of his share of the water, and as the needs of the people are not great at present (it being a new canal) the methods of distribution are wasteful, and water has a very low duty.

While believing in the ownership of canals by their users, I must admit that the me[illegible] [illegible]tion practiced under this one is ill advised. It is [illegible] which was shown by these

Duty of water at Station No. 3, Boise Valley.

Month.	Area.	Water used.	Depth.
	Acres.	*Acre-feet.*	*Feet.*
June	74	29.82	[illegible]
July	74	35.44	[illegible]
August	74	30.89	[illegible]
September	74	13.06	[illegible]
Total	74	109.21	[illegible]

The maximum irrigating head used at any one time was 0.83 cubic foot per second or 41.5 inches, and the average head was 0.61 cubic foot per second or 30.5 inches. The orchard was divided into several tracts, which were irrigated by rotation in from four to eight days.

An automatic register made a continuous record of the depth of the water flowing in the supply lateral as it passed over a trapezoidal weir.

Duty on grain and miscellaneous crops.—No measurements were made this season for the determination of the amount of water used in the irrigation of grain in the Boise Valley. Four irrigations between seedtime and harvest will usually more than suffice. Assuming that 2 cubic feet per second are used in the irrigation of 40 acres of grain, and that three days are required for each application, the total volume employed is 47.6 acre-feet, or enough to cover the tract to a depth of 1.19 feet. Provision should be made for the application of one-half this amount during the hottest part of the growing season, which is usually during July. The last irrigation of grain usually occurs before the 1st of August, or before the river has reached its low-water stage. Potatoes require from one to three irrigations; corn and other crops planted in rows require water from two to four times during the growing season. When the surface is carefully prepared, crops planted in rows may be easily irrigated and do not require a large

deep, and discharged, June 25, 1899, 75 cubic feet per second. The outcome of this project has been disappointing. It has not paid as an investment, and it irrigates only one-tenth of the land it covers.

The enterprising people of this community have now decided to organize an irrigation district, purchase this canal, and enlarge and improve it until it will water 12,300 acres. This will necessitate the construction of a canal 24 feet wide on the bottom. It will carry 223 cubic feet per second of water, or 1 cubic foot per second for each 55.1 acres irrigated. The estimated cost of the canal, when enlarged, is less than $55,000, and it is believed that water can be furnished by it for less than 40 cents per acre per annum. Under the provisions of the irrigation district law an acreage assessment must be levied for the payment of the interest on and redemption of the bonds, but tolls may be charged for the delivery of the water, to be based upon the quantity delivered. This latter charge will be for the payment of the cost of distributing the water. It is hoped in this way to distribute the charges equitably, holding all land in the district liable for the payment of the bonds, but placing a part or all of the expenses of maintenance upon the users of water. These expenses will be for the wages of one water-master and his assistants, the salary of a secretary, whose duties will be very light, the repairing of gates, and the occasional cleaning out of the canal. The plan is to build a canal of ample size and capacity, employing good methods in construction with a view of saving a large part of the annual maintenance expenses.

Owing to the location of the point of diversion of this canal it will be one of the first to profit from the return or seepage water to the river. It is thought that the seepage water which accumulates above this point will insure a steady and increased flow of the river during its low stage. The canal crosses Ten Mile and Indian creeks a short distance above their mouths, and it is intended that it shall catch the waste water flowing in these streams.[1]

Sebree Canal.—This canal heads in the Caldwell Canyon, and waters land lying on the north side of the river. At a quarter of a mile below its headgate it is 31 feet wide at the surface of the water, 22 feet wide on the bottom, 3.2 feet deep, and carried on June 24, 1899, 165 cubic feet per second. It irrigates about 6,000 acres of land.

The canal was first built by the Idaho Irrigation and Colonization Company. It has since been enlarged in accordance with an arrangement with the landowners. The original builders charge for the delivery of water by the quantity, but owing to its small capacity the

[1] Since the above was written the people living below the level of the Phyllis Canal have joined with those under the Caldwell ditch and are preparing to organize an irrigation district which will embrace all the land lying below the line of the two canals. a [illegible] oject has great merit and will undoubtedly be a succe[illegible]

property was never on a paying basis. After a great deal of disappointment on the part of both water users and investors, it was agreed to allow the farmers to "work out" an interest in the project, and the small ditch was accordingly enlarged to its present capacity.

It seemed to be the understanding of the landowners that water would be delivered to them at actual cost, but after the work had been performed a difference arose with the original company, which had not been dissolved. The company retained the control of the ditch and fixed the charges for maintenance according to its own ideas. The farmers claimed these were being arbitrarily increased from year to year and have finally taken the matter into court for settlement.

Riverside Canal.--The point of diversion of this canal is only a few feet above that of the Sebree ditch on the south side of the river in the Caldwell Canyon. From the headgates it runs along the first bottom of the river for a distance of nearly 10 miles, when it reaches the first bench, where the first delivery of water is made. It is 14 feet wide on the bottom and carries at present about 50 cubic feet per second of water.

The Boise Land and Water Company, the owner of this property, was organized in 1892, and a ditch was built and water delivered onto the land during the season of 1893. The original plan of this company contemplated the selling of "perpetual water rights" at the rate of $10 per acre with an annual maintenance charge of $1 per acre. Early in the year it was believed that this system would prove a failure, so a second company called the Riverside Irrigation District, Limited, was organized. This company bought the canal and issued to purchasers of water a proportionate amount of stock in the Riverside Irrigation District, Limited. The rights to the water are dedicated to described lands and the stock only represents the right to participate in the affairs of the company, the intention being to make the irrigators the managers of the property. It would seem by the arrangements made that it would be impossible to separate the water from the land even if the stock of a landowner were to be sold under an attachment. These shares sell for the uniform price of $10 each, one share to each acre of land.

While the owners of stock in the Riverside company do not at present possess a majority of shares, yet the management of the canal has been turned over to them entirely, and they now obtain their water at the actual cost of maintenance.

No one has suffered through the workings of this scheme. The builders of the canal are making a reasonable profit through the returns from the stock and land. By making a liberal contract for the use of water, the company has so strengthened its position that it has at all times received the hearty support of the settlers. This com-

munity is thrifty and peaceful and has had a steady growth. Water is at present delivered to 2,000 acres of land. Measuring gates are not used at present, although it is the intention to adopt them next season. The right is reserved in the by-laws of the company to establish a system of distribution by rotation whenever it shall be deemed necessary. While no fears are entertained regarding the water supply for this canal, yet a more orderly system for its distribution would be a great gain to the people. The first step in the reform would be to base assessments for maintenance on the amount actually used.

A better point of diversion for the Riverside and Sebree canals could not have been chosen. The lava dike which forms the Caldwell Canyon forces the seepage water to the surface near this place and insures a steady and increased supply in the river during its low stage. Nearly 15,000 acres of land will be ultimately served by the Riverside Canal, and about 20,000 acres of land will one day be watered by means of the Sebree Canal.

Smaller ditches.—All the canals just described conduct water onto the bench lands, although some serve land located on the first bottom. A great number of short ditches built by the landowners water the lands of the first bottom. Some of these ditches belong to associations of farmers, who work out the annual assessments levied for maintenance expenses. The construction of these canals has cost from $2 to $4 per acre for the land watered by them, and the annual cost for maintenance is from 15 to 50 cents per acre. The regulations governing the use of water from these ditches have had but little effect in promoting economy. A large body of valuable land is being ruined by overirrigation. Drain tiles are needed as badly on the first bottom of the river as irrigation canals on the bench lands. The cheapness with which water may be obtained in some localities is not without its drawbacks, as it leads to overirrigation and renders valuable fields unfit for cultivation.

A detailed description of the location and management of these canals has been given because the duty of water depends on other things than rainfall, soil, or the crops grown. Among the factors which determine the area which a cubic foot per second will irrigate are the nature of the water contract and the spirit of cooperation which exists among the irrigators. Until selfish irrigators at the head of the river or at the head of the ditch are compelled to regard the rights and interests of other users, those above will waste water and those below will have to take what is left.

In describing the defects of the system now in use it is hoped to create a public sentiment in favor of more economic distribution and secure a higher duty than an inch to the acre. It is believed that this is not only the educational movement should be

begun at once in order that it may influence the final adjustment of rights and limit appropriations to the quantity actually used. Those who favor the continuation of old methods, which disregard the right of the later and lower users, should remember the benefits which will come to the community and State through an economical administration which will permit of the reclamation of thousands of acres of desert land lying below the levels of the canals already built.

DUTY OF WATER.

If asked how much water is required to irrigate a given amount of land in the Boise Valley I should be compelled to answer, "I do not know."

The gathering of facts on which to base an answer to this inquiry was made in the season just closed. With this purpose in view three stations were established in the Boise Valley, all of which are on the Boise and Nampa Canal, as shown on the map (Pl. XLIX, p. 220). Water was used in the usual manner, being turned on and off according to the ideas of the irrigator, or allowed to flow continuously if thought necessary.

Station No. 1.—The Rust Lateral, which serves a large body of land situated in one of the oldest portions of the bench, was selected for this investigation. From a daily record of its flow the amount of water delivered to users was determined. The greater portion of the tract was devoted to old meadow (alfalfa, timothy, and clover), and the remainder was seeded to grain (oats and wheat). The discharge of the lateral was computed from daily reports of the water master on the main canal. He measured the head of water and the height of the opening in the gate twice each day, from which the volume of water flowing in the lateral was determined. These reports began on May 1 and ended September 30. Water was used after this date, but no record was kept of its flow. While occasionally the meadows are improved by irrigation during the month of October, rainfall usually supplies all needed moisture. The record covers the extreme limits of the usual irrigating season.

The lateral in question delivered water to 790 acres of land, the property of eighteen owners. Each owner ordered and paid for the quantity of water which, in his estimation, the crops would need. The lateral has a large fall and is short, hence the loss from seepage and evaporation is slight. The ground is favorably situated for irrigation, since a large head of water may be passed over the surface in a short time without any danger of washing or cutting. The surface could be easily prepared for irrigation by means of the check system. The following table shows the daily discharge of the lateral for the season:

Water delivered from the Boise and Nampa Canal through the Rust Lateral to eighteen users near Boise, Idaho, season of 1899.

[See diagram, Pl. XXIII, p. 80.]

Day.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	24.58	29.38	28.20	29.70	27.84
2	25.54	29.90	28.44	28.70	25.92
3	25.54	21.84	29.92	26.02	27.36
4	13.90	18.60	29.20	28.80	27.00
5	15.12	18.80	28.44	29.00	27.56
6	14.48	27.82	28.44	29.00	21.22
7	14.48	27.08	28.92	28.40	21.60
8	13.90	28.30	28.92	26.02	20.88
9	13.50	32.40	28.32	27.10	21.24
10	13.50	27.80	27.90	27.42	26.54
11	13.40	28.44	28.56	27.10	26.54
12	13.90	28.30	30.92	25.60	26.54
13	13.40	28.58	30.08	28.80	27.00
14	18.72	27.44	29.06	27.60	26.10
15	19.52	28.00	28.60	27.60	26.76
16	20.88	30.20	25.64	27.10	26.76
17	25.44	28.70	28.30	26.24	25.84
18	24.96	28.18	27.60	26.02	26.54
19	25.92	28.42	28.00	26.48	26.38
20	25.44	31.20	27.20	27.66	27.22
21	25.44	27.50	25.64	27.66	26.10
22	25.44	29.20	26.54	27.66	26.10
23	....	29.70	27.00	23.48	27.44
24	24.14	28.18	24.00	23.48	26.76
25	28.30	28.70	....	23.60	27.44
26	25.20	28.70	28.80	24.50	27.22
27	25.44	27.94	28.80	24.50	27.22
28	25.80	28.80	28.90	24.30	26.76
29	26.40	28.00	25.48	21.24	26.54
30	27.36	29.20	25.48	24.78	25.10
31	25.44	....	25.48	24.78	....
Total	635.08	855.30	906.78	820.34	779.52

As shown by the table, the total discharge for the season was 3,997.02 acre-feet. This gives the following duty for the water discharged by the lateral:

Duty of water under Rust Lateral.

Area irrigated	acres..	790.00
Discharge of lateral	acre-feet..	3,997.02
Depth of irrigation	feet..	5.06
Depth of rainfall	do...	.22
Total depth of water received by land	do...	5.28
Area irrigated per cubic foot per second	acres..	57.48

It will be observed that during the first half of May only about one-half the usual amount of water was used. After that period there was but little change in the flow until September 30, the end of the season. The average daily flow of the lateral for this period of 153 days was 13.1 cubic feet per second, or about 1 cubic foot per second for each 57.5 acres of land irrigated. This flow of water, if spread out evenly over the surface of the tract of 790 acres, is equivalent to an avera [illegible] 8 foot, or nearly two-fifths of an inch.

Later on, attention will be called to a notice sent to the users of water under this canal, wherein they are advised to economize in the use of water by adopting a system of "rotation" or the use of a large irrigating head of water in turn. It is quite evident that this system of distribution was not adopted, for had it been, one-half the quantity of water which was turned through the headgate of the lateral would have sufficed. Still, the quantity of water turned into the lateral was ordered by the farmers in the spring, and paid for notwithstanding its waste. A comparison with the results secured at another point in the valley will show that a system of distribution might have been adopted which would have saved fully one-half of the water used.

Station No. 2. The water used on the farm of Mr. A. F. Long was carefully measured over a trapezoidal weir, the depth being recorded by an automatic register from the 7th day of June to the 30th day of September. This land is situated about 5 miles southeast of Nampa, under one of the upper laterals of the Boise and Nampa Canal, and is marked on the map as Station No. 2 (Pl. XLIX, p. 220). The tract supplied with water is favorably situated for irrigation, and previous to seeding it was properly leveled, an effective system of laterals was constructed, and preparations were made for handling a large head of water at a minimum outlay of time and labor. The cultivated portion of the farm consists of 15 acres of alfalfa, seeded in 1898, 50 acres of alfalfa and clover, seeded in 1899, and a 40-acre prune orchard, planted in 1894, or 105 acres in all. In the spring Mr. Long contracted with the irrigation company for 100 inches or 2 cubic feet per second of water. For this he paid $150, with the understanding that he was to turn off the water when it was not needed on his land. The terms of this contract were the same as those entered into by the users of water from the Rust Lateral. One advantage enjoyed by the users of the Rust Lateral and not enjoyed by Mr. Long was that, owing to the great number of water users and the large head of water carried by their common lateral, every opportunity was afforded for a splendid system of rotation. Mr. Long, being the only user of water near this point of delivery on the canal, was obliged to order an irrigation head large enough for the greatest need at any one time, rotating from one tract to another on his own land, but receiving no credit when he turned the water back into the main canal. He paid for a continuous flow, fixed by the character of the crops grown and the area devoted to each, without regard to whether he used the water all the time or not. The following table shows the quantity of water used by Mr. Long and the time of its use:

Water used by A. F. Long, near Nampa, Idaho.

[See diagram, Pl. XXV, p. 80.]

Day.	May.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	1.81	3.07	....	3.24
2	....	1.81	3.38	0.01	1.67
3	....	1.81	3.77	.90	1.54
4	....	2.20	3.51	1.49	2.47
5	....	1.47	3.51	1.17	2.83
6	0.38	2.70	3.13	.80	....
7	.38	1.53	3.25	.81	....
8	.38	1.29	2.98	.78	2.95
9	.38	2.79	2.57	.27	1.57
10	2.66	1.69	3.48	.25	
11	2.75	.76	2.58	.25	....
12	2.84	3.38	3.17	....	....
13	2.84	3.38	3.35	....	....
14	....	3.38	3.42	....	....
15	....	3.64	3.63	....	1.61
16	....	3.90	3.64	....	1.57
17	....	3.53	3.74	....	....
18	....	3.01	3.77	....	....
19	....	2.53	3.74	....	....
20	.46	3.01	3.27	....	....
21	....	3.13	3.04	....	....
22	....	2.24	2.87	....	....
23	....	.01	3.85	3.51	.53
24	....	1.73	3.80	3.68	1.27
25	....	3.25	3.73	3.38	1.27
26	....	4.22	.75	1.69	.90
27	1.91	4.44	.99	.88	.59
28	1.79	3.64	3.69	3.31	.62
29	1.83	3.38	1.96	3.39	.36
30	2.50	3.51	....	3.38	.03
31	2.08	....	....	3.44	....
Total	23.18	79.17	91.64	33.39	25.02

Irrigation was begun on May 6, lasting for but a week, and did not begin again until the 27th, when only a small head was used until June 11. The exact record of the quantity of water used and the place of its use was begun on June 7, which record was kept to September 30. The head was reduced from June 7 to June 10 and was all used for the irrigation of a meadow of 15 acres, seeded in 1898, designated "old" meadow, as against "new" meadow, seeded in 1899. The amount delivered during this time was 7.29 acre-feet, which is sufficient to cover the land to a depth of 5.84 inches. The entire head, after being increased on the 11th, was turned onto 25 acres of new meadow, where it was used for nine days. The total volume furnished this tract was 27.49 acre-feet, or enough to cover it to a depth of 13.2 inches. The head was then reduced and turned on to the orchard tract of 40 acres, which required for its first irrigation 10.12 acre-feet, or a depth of about 3 inches. From the 25th of June until the 25th of July there was but little change made in the head of water drawn from the main canal; from the 26th to the 29th the head was reduced, and turned off entirely on the 30th. A small head of water was used in turn from August 2 to August 11 in the irrigation of old and new meadow tracts, and from that date until August 22 water was not used. Rain fell from August 14 to 25 to a total depth of 0.083 foot, or about 1 inch. Beginning with the 23d of August, water was applied to the orchard for five days, concluding its irrigation for the season. An

increased head was then turned on to 20 acres of new meadow, and on September 3 it was changed to the old meadow. On the 6th and 7th of September a large head of water was allowed to run to waste. Small heads were intermittently used on meadow land during the remainder of the month of September. The following table shows the water used on the various crops, by months and for the season:

Water used on various crops during the season.

Crop.	Area.	Number of irrigations.	May. Quantity.	May. Depth.	June. Quantity.	June. Depth.	July. Quantity.	July. Depth.
	Acres.		*Acre-feet.*	*Foot.*	*Acre-feet.*	*Feet.*	*Acre-feet.*	*Feet.*
Old meadow	15	6	....	....	7.30	0.49	17.37	[illegible]
New meadow	50	[1]	23.18	0.46	61.75	1.24	46.87	[illegible]
Orchard	40	4	....	....	10.12	.25	27.40	[illegible]
Total	105	....	23.18	.22	79.17	.75	91.64	[illegible]

Crop.	Area.	Number of irrigations.	August. Quantity.	August. Depth.	September. Quantity.	September. Depth.	Total. Quantity.	Total. Depth.
	Acres.		*Acre-feet.*	*Foot.*	*Acre-feet.*	*Foot.*	*Acre-feet.*	*Feet.*
Old meadow	15	6	2.66	0.18	8.37	0.56	35.70	[illegible]
New meadow	50	[1]	17.59	.35	16.65	.33	166.04	[illegible]
Orchard	40	4	13.14	.33	....	....	50.66	1.2[illegible]
Total	105	....	33.39	.32	25.02	.24	252.40	[illegible]

[1] Indeterminate.

We observe from the above table that the new meadow required the most water during the month of June, while the old meadow and the orchard demanded the most during the month of July. The period of greatest demand for all crops was during the month of July, when a depth of 0.87 foot was required, which was about one-third of the total amount used during the entire irrigating season. The orchard required a total depth of 1.27 feet, 54 per cent of which was applied during the month of July. The average depth used on the meadow was 3.09 feet, although the depth of 2.38 feet will perhaps be sufficient after the first year; 3.32 feet for the new meadow is excessive. A safe estimate of the quantity of water needed for the proper irrigation of alfalfa would be 2.5 acre-feet per acre, and the supply must be such that at least 1 per cent of it may be had each day during a period of thirty days in the months of July and August.

As before stated, 50 acres of this land was seeded in the spring of 1899 to clover and alfalfa. It is unusual to obtain a cutting from a meadow of this kind during the first season of its growth, yet in October of this year 50 tons of hay were cut from 40 acres. It is needless, therefore, to state that it had received sufficient water for its irrigation.

Mr. Long states that after the water had been running over the surface of his meadow for a few days nearly as great a quantity of waste water ran off at the lower end of the field as was turned on at

the upper. The determination of the exact amount of such waste will. it is hoped, be undertaken next season.

Station No. 3.—Station No. 3 consists of an apple orchard of 74 acres, the property of Hon. Edgar Wilson. The ground was carefully prepared before the trees were planted, and the cultivation and care of these orchards has ever since been thorough. A portion of the orchard has been in bearing for two seasons past. Water has been applied with great care, and the best results as to quantity of fruit and growth of trees have been attained.

The first irrigation of the orchard began on the 7th of June, during which month 29.82 acre-feet of water was used. Quite a uniform flow was used during the month of July, a total of 35.42 acre-feet, and continued with but slight diminution until about the 15th of August, when the irrigation of the older and bearing portions was suspended for a time or until the fruit buds became properly set. In order to impart color and promote the healthy maturing and ripening of the apple crop, water was again turned onto the bearing portion of the orchard and allowed to run from August 26 until September 5, and again from the 11th to the 16th of September.

The following table shows the quantity of water in acre-feet used each day during the irrigating season. The depth given assumes that this amount had been spread evenly over the tract of 74 acres, thus affording means for a comparison with results at Stations 1 and 2:

Water used on the orchard of Hon. Edgar Wilson, near Boise, Idaho, season of 1899.

[See diagram, Pl. XXIV, p. 80.]

Day.	June.	July.	August.	September.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
1	....	0.47	1.38	1.60
2	....	.93	1.14	1.55
3	....	.93	1.46	1.50
4	....	1.03	1.44	.80
5	....	1.07	1.62	.42
6	....	1.27	1.66	.18
7	0.66	1.44	1.55	....
8	.96	.60	1.25	....
9	.96	1.31	1.43	....
10	1.32	1.36	1.49	....
11	1.34	1.45	1.19	.92
12	1.00	1.19	1.04	1.52
13	1.34	1.17	.90	1.42
14	1.34	1.09	1.01	1.29
15	1.00	.47	.93	1.26
16	1.34	1.29	.91	.60
17	1.00	1.16	.73	....
18	1.36	1.11	.75	....
19	1.90	1.11	.35	....
20	1.38	1.39	....	....
21	1.38	1.44	....	....
22	....	1.42	....	....
23	1.72	1.37	....	....
24	1.36	1.32	....	....
25	1.40	.47	....	....
26	1.72	.57	.68	....
27	1.34	1.24	1.60	....
28	1.32	1.41	1.53	....
29	1.34	1.40	1.52	....
30	1.34	1.47	1.67	....
31	....	1.47	1.66	....
	29.82	35.44	30.89	13.06

tracts, which were irrigated by rotation in from four to e

An automatic register made a continuous record of the water flowing in the supply lateral as it passed over a trap

Duty on grain and miscellaneous crops.—No measure made this season for the determination of the amount of w the irrigation of grain in the Boise Valley. Four irrigati seedtime and harvest will usually more than suffice. Assu cubic feet per second are used in the irrigation of 40 acr and that three days are required for each application, the employed is 47.6 acre-feet, or enough to cover the tract t 1.19 feet. Provision should be made for the application this amount during the hottest part of the growing seas usually during July. The last irrigation of grain usu before the 1st of August, or before the river has reached i stage. Potatoes require from one to three irrigations; co crops planted in rows require water from two to four t the growing season. When the surface is carefully prep planted in rows may be easily irrigated and do not requ volume of water, as the irrigating head is divided int threads, one being applied to each row to be watered. mate of the quantity needed for these and other miscella whose growing season is short would be a depth of 1.25 fe of which should be provided for during thirty days of season, or from June 15 to August 15.

COST OF WATER.

Although Mr. Long used water with care, turning it back into the main canal when it was not needed, he paid more for it by the acre, and nearly two and one-half times as much per acre-foot used, as was paid by the irrigators under the Rust Lateral. Mr. Wilson, who required but a small volume or irrigating head for each irrigation of his orchard, paid a little more per acre, and nearly three and one-half times as much per acre-foot for the quantity of water actually delivered to him, as did the irrigators under the Rust Lateral. It might be well to state here that the maximum irrigating head used by Mr. Wilson did not exceed 0.8 cubic foot per second; therefore he was to blame for ordering more water than he needed. Had he paid for only the maximum head used, an acre-foot would still have cost him more than twice as much as was paid by the irrigators under the Rust Lateral. Had a reasonable charge been made for the delivery of this water by the acre-foot and a system of rotation in the use of serviceable irrigating heads been planned and enforced by the management, more than twice the area might have been irrigated from the Boise and Nampa Canal this season and the revenue of the company greatly increased. No industry demands as close cooperation on the part of those employed in it, as does farming by means of irrigation. The works which convey water to large bodies of land are necessarily expensive. The cost of maintaining and operating a canal varies but little after a certain capacity is reached. Whether water is sold by a fixed charge per acre irrigated or at so much per cubic foot per second, there is a tendency toward wasteful use. To encourage economy in irrigation water should be sold by the volume used, employing a definite unit, such as the cubic foot or the acre-foot. When a charge is based upon a certain volume flowing continuously during the season, delivering water by rotation can not be enforced by the management, and can only be entered into voluntarily by the users.

DISTRIBUTION OF WATER.

Often on small streams the area of land reclaimed is so great as to seem out of all proportion to the water supply. Harmony may prevail among the irrigators, while on a neighboring large stream the people may be in continual turmoil and litigation over water rights. On the streams first mentioned the irrigators regard the water supply as common property, no one claiming to have a superior right. The opposite of this equitable system may be established on streams having a water supply in excess of the needs of the first users. With only their present needs in mind, every irrigator claims the right to the continuous flow of a certain volume of water. Upon these claims a system of administration of canals and distribution of water is founded, whi[illegible] fact that the public is as much benefited by th[illegible] a large as of a small stream.

[illegible] necessary to maintain a continuous flow in the large canals diverting water from the Boise River, for the canal is to the many irrigators along its course what the smaller stream is to those who divert water from it by means of individual ditches. Being their [illegible] of supply, [illegible] of its flow would be as damaging in its effect as the [illegible] of the stream.

[illegible] FOR THE DELIVERY OF WATER BY THE ACRE AND ITS EFFECT

[illegible] canals in the Boise Valley, which were operated [illegible] fixed a price for the delivery of water at a certain amount per acre. Then a change was made. In order to explain the character [illegible] must be described.

On some of these canals no attempt was made to measure the volume [illegible] and in many instances the amount was estimated. As a rule there was no orderly system of distribution adopted, the practice being to keep the main laterals [illegible] and [illegible] from a common lateral [illegible] among themselves. Near the lower end of long laterals supplying [illegible] for the irrigators to "rotate" in the use of the water reaching them, in order to save their crops. No reduction in price was made on this account, the water costing the same whether a scant or an abundant supply was furnished. It was not surprising, therefore, that every irrigator demanded the full allowance for his land, whether his crops needed it or not.

This practice led to many extravagant ideas regarding the duty of water. There is always an abundant supply during the flood season, but during the period of low water a shortage is liable to occur. As a preparation for this, irrigators were allowed to use all they wanted during the season of plenty. Many took advantage of this license and kept their ditches bank full, saturating the low places on their farms. If the Boise Valley received an annual rainfall of 60 inches or over, drainage would be necessary on all the low land along the river. The excessive use of water in irrigation has had the same result. Waste water has been allowed to flow down every drainage way and collect on every low piece of land lying along its course, and the only individual who has been thoroughly satisfied with the result is the sportsman—wild ducks having become more plentiful on this reclaimed land.

In justice it should be said that many farmers are pursuing better methods, constructing splendid lateral systems, properly leveling their fields, until many farms show the effect of the skill and good taste of their owners. But even this class of farmers have suffered from the wrong system of distribution, for the effort to guard against the selfishness of the slovenly irrigator has led to the building of numerous individual laterals from the main canal and a further loss by deliv

ery of water through several channels, where one would have served better.

The practice of charging for water by the acre not only encouraged wasteful methods in irrigation, but was also, in addition, an inequitable proposition. It compelled the painstaking, thrifty farmer, who had leveled his fields in order to save water, to pay the same price per acre as the man who had not done so.

CHANGE IN STATE IRRIGATION LAW.

The legislature, in 1899, enacted a law to require payment for water by quantity and to secure a more equitable division in other respects. The section referred to is quoted:

SECTION 20. Any person or persons owning or controlling land which has or has not been irrigated from any such canal shall, on or before January 1 of any year, inform the owner or person in control of such canal whether or not he desires the water from said canal for the irrigation of land during the succeeding season, stating also the quantity of water needed. In distributing water from any such canal, ditch, or conduit during any season preference shall be given to those applications for water for land irrigated from said canal the preceding season, and a surplus of water, if any there be, shall be distributed to the lands in the numerical order of the applications for it. But no demand for the purchase of a so-called "perpetual water right," or any contract fixing the annual charges or the quantity of water to be used per acre, shall be imposed as a condition precedent to the delivery of water annually, as provided in this act, but the consumer of water shall be the judge of the amount and the duty of the water required for the irrigation of his land; and annual charges, to be made and to be fixed under the further provisions of this act, shall hereafter be based upon the quantity of water delivered to consumers, and shall not, in any case, depend upon the number of acres irrigated by means of such amount of water delivered.

With but few exceptions this practice of charging by the acre was confined to the Boise Valley when the above law was enacted, the Boise and Nampa, the Settlers, and the Phyllis canals having been operating under that system. As these canals must be depended upon for the irrigation of the greater portion of the reclaimable land in the valley, their management is of great importance to those who wish to promote the prosperity of this section.

The law compelling the delivery of water by quantity was designed to become operative during the season of 1900. The following notices, sent out to water users shortly after its enactment, show how it was viewed by ditch owners in the Boise Valley:

OFFICE OF ——— CANAL,
Boise, Idaho, March 1, 1899.

NOTICE TO CUSTOMERS:

The water rent for the irrigation season of 1899 will be at the rate of seventy-five dollars per cubic foot of water per second, payable November 1, 1899.

Positively no applications will be accepted nor water delivered for any land in arrears for water rent until such arrears are settled.

No water w[illegible] lateral used by two or more customers, nor will the car[illegible]lity, until a water master has been appointed and th[illegible]intment.

(5) Under such administration the farmer would carefull the surface of his fields in order that the water might be the shortest possible time. He would endeavor to dete quantity of water actually required to produce the best resul an interest would be encouraged in the more accurate and features of farming, which are always of incalculable benefi community.

(6) The inauguration of a uniform system of rotation wou increase the duty of water and proportionately reduce th irrigation. In order to properly carry this into effect, lat boxes should always be in good condition.

(7) When this system is established, irrigation on eac reduced to a routine, every farmer knowing in advance w head of water he is entitled to and the length of time it will his land. Under this plan he is also afforded an incentive the amount used by improving his methods of cultivatic distributing the water after it enters his fields.

(8) The company should construct a drainage system th the entire district connecting all swampy places with natu ways, and the water thus drained from the land should be control for distribution.

same revenue as the rate per acre formerly charged. As the canal has been carrying its full capacity for two years, the farmer only could profit by this arrangement. The company has tried to measure all the water delivered this season, and the new system has given general satisfaction. Immediate recovery from the effects of the injurious system under which the canal had been conducted for over eight years was not anticipated.

The second notice stated that the price for the delivery of water for the season of 1899 "will be at the rate of $225 per cubic foot per second, continuous flow for the season, or upon the applicant waiving the right to demand water by quantity, at the rate of $1.50 per acre."

The great importance attached to the condition of a continuous flow for the season does not seem warranted when it is further agreed that the water is to be used only when required. No one would be benefited by allowing valuable water to run to waste. The second rate, $1.50 per acre, is the minimum price which will be accepted. At this rate the irrigator can cover his field to a depth of 2 feet. If this is exceeded an additional payment must be made at a proportional rate. Under this arrangement one farmer might cover his land to a depth of 4 feet, which would cost $3 per acre. Another might cover his land to a depth of but one-half of a foot. The latter would have to pay $1.50 per acre, or four times as much for the same quantity as the former. This is manifestly unjust. When water is sold by the volume, the rate should be uniform.

The notice provides that "when water is delivered by the cubic foot per second the flow shall be continuous as far as possible, and the amount contracted for will be the maximum amount that will be delivered at any one time."

The most ignorant irrigator realizes that a continuous flow of water, like a continual downfall of rain, would be injurious. Under this arrangement the small farmer who might otherwise economize is discouraged. He is compelled to pay for the greatest quantity used at any one time, no matter how brief the duration of such use. He must therefore pay for enough to cause it to flow quickly over his field, otherwise the attempt to irrigate would be like a drizzling rainfall lasting from spring till autumn, but not heavy enough at any time to wet the soil.

It is galling to the irrigator who notifies the management at the beginning of the season that he will require the same amount of water he used in previous years for the irrigation of a larger area to have this acreage carefully measured at the close of the season and his bill for the delivery of water proportionately increased.

A careful analysis of this notice shows that the distribution of water [illegible] this system is diametrically opposed to every voluntary [illegible]rator to secure a higher duty.

The irrigated area of the Boise Valley has increased from about 27,000 acres in 1895 to 50,000 acres in 1899. The increase of area has been chiefly on the upper or bench lands. The water conducted onto these benches (especially on the south side of the river) has been distributed to a great distance from the river, therefore the return of the water taken up by the underlying gravel was not noticed until within the last two or three years. The following incident illustrates the changed conditions resulting from this seepage.

In 1891, the promoters of the New York Canal proposed to divert nearly all the water of the Boise River at a point in the Boise Canyon and irrigate all the lands lying on the south side of the river below the level of that line. (See Map, Pl. XLIX, p. 220.) The following protest against the building of this canal, copied from the public records of Ada County, shows the apprehensions of those constructing canals and diverting water from the river in the Caldwell Canyon, 40 miles below:

Idaho Irrigation and Colonization Company to Idaho Mining and Irrigation Company.

The Idaho Irrigation and Colonization Company to the Idaho Mining and Irrigation Company and to whom it may concern, greeting:

Whereas it has come to our knowledge that a certain company, viz, The Idaho Mining and Irrigation Company, has projected and intends to the construction and enlargement of certain canals and ditches, viz, the so-called New York Canal and the Phyllis Canal, with the object of taking and diverting water from the Boise River in the State of Idaho for irrigating, mining, and other purposes; and whereas we believe that all the water running in said river in time of low water has been filed upon and appropriated by individuals and companies whose priority of claims and appropriation must and will be guarded and protected; and

Whereas we believe that the great expense to which said Idaho Mining and Irrigation Company would be at in construction and enlargement of said canals would result in great loss to said company because of lack of water in the Boise River heretofore appropriated by prior claimants to supply said canals and ditches constructed and enlarged as intended:

Therefore said Idaho Mining and Irrigation Company will please take notice that we have appropriated 20,000 cubic inches, measured by the mining laws of the United States and State of Idaho prescribed, of water running in the said Boise River for irrigation and agricultural purposes; that in time of low water there is barely sufficient unappropriated water running in said river to supply our claim; that any diminution in this supply by appropriation subsequent to our own will be resisted; that we now warn said company that any taking or diverting of waters from said Boise River in canals and ditches constructed and enlarged as intended by said company will cause a diminution of water appropriated and used by us, and therefore that the proposed construction and enlargement of canals and ditches by said company is unwarranted and the taking and diverting of water as intended will be unlawful and the great expense incident to said work must result in great financial loss to said company.

IDAHO IRRIGATION AND COLONIZATION COMPANY.

This protest was filed in 1891. At that time not more than 4,000 acres of bench land were irrigated from the Boise River. The plans of the company referred to contemplated the construction of storage

average combined irrigating head of these canals at 1,4
per second. This volume irrigated 50,000 acres during 1
was, of course, considerable loss from seepage and evapo
main canals and laterals during the hottest weather. Thi
been determined, but from the nature of the soil loss f
could not have been very great. Assuming, however, t
bined loss is equal to 30 per cent of the volume diverted fr
the net supply delivered at the fields for irrigation would
feet per second. This allows an average duty of 51 ac
cubic foot per second of water diverted. Nine hundred
cubic feet per second flowing onto 50,000 acres of land f
days will cover it to a depth of 1.21 feet. We find that
under the Rust Lateral used during the month of July, 1
of 1.15 feet, which approximates the average duty obtai
out the valley. In the case of Mr. Long, however, we find
of 0.872 foot during the month of July was sufficient.
the methods employed by Mr. Long were not unusual, it
sonable to insist that 32 per cent more land under the 1
could have been irrigated during that month with the s
water. When the available supply in the river is only 1,2
per second there should be sufficient water to properly ir
acres, after deducting 30 per cent due to loss from seepag
oration. This would require a duty of 70.5 acres for eac
per second of water applied to the land. No account is t
the amount which runs off the land during its irrigation.
collected in drainage ditches and applied to the lower lan
gated area might be increased by perhaps 30 per cent.

there will be left 706 cubic feet per second for the irrigation of grain, which will mature before the low-water stage is reached. Assuming that each cubic foot per second of this water will irrigate 64.1 acres, it will be sufficient for the growth of 45,254 acres of grain, making in all 128,254 acres which might be watered. This estimate will, perhaps, seem high to many irrigators in the valley, but this is because they have become accustomed to the waste which is now so prevalent.

The Boise and Nampa Canal delivered daily 700 acre-feet of water to only 17,100 acres, equivalent to a depth of 1.27 feet during both July and August, or to a daily rainfall of nearly one-half an inch.

The Settlers' Canal delivered 180 acre-feet daily on 5,000 acres. Being a short canal, the loss from seepage and evaporation was slight. This was equal to a layer 1.13 feet deep in both July and August.

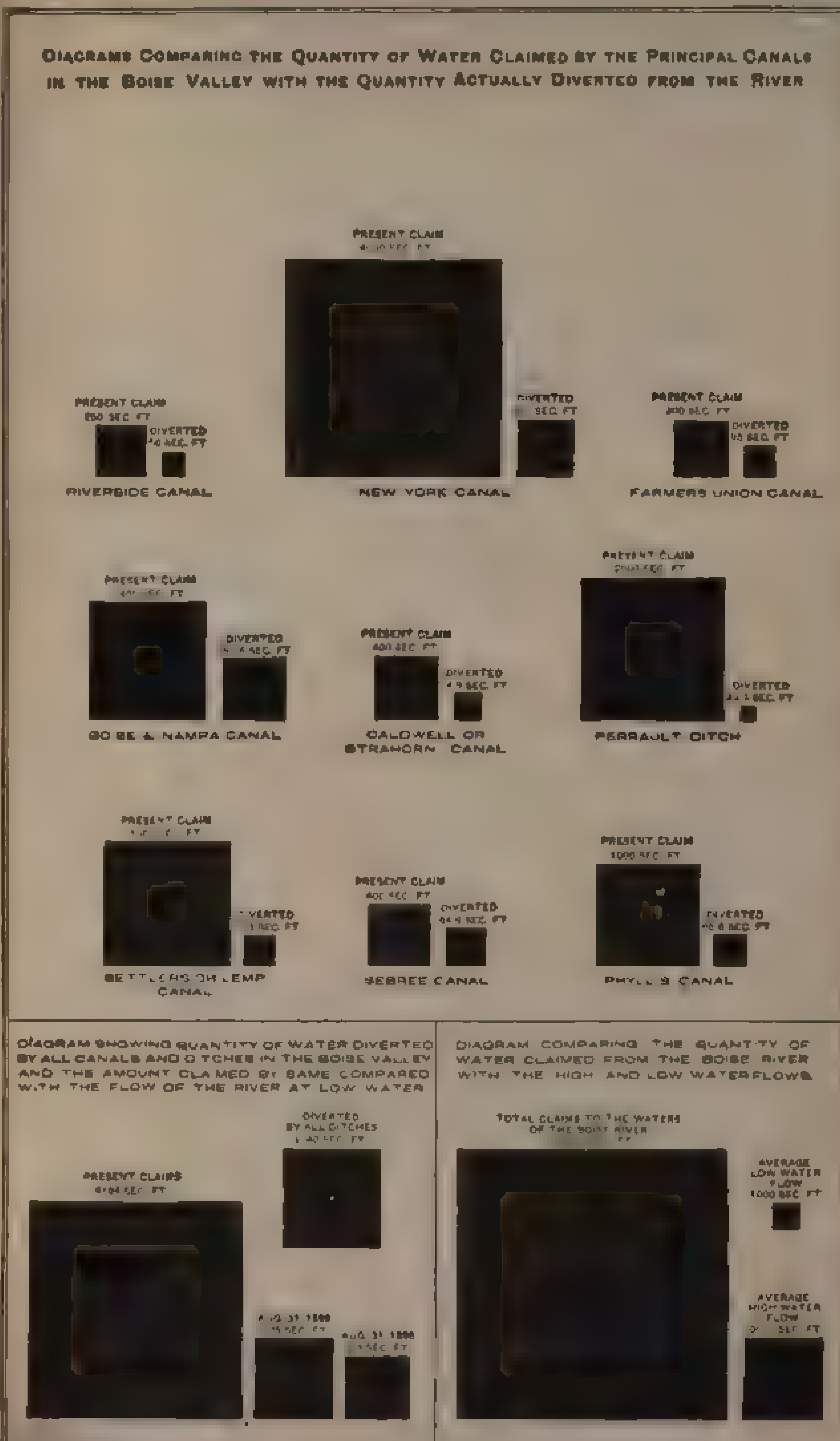
Assuming that the Phyllis Canal discharged daily 160 acre-feet during both July and August, there was delivered to the 3,000 acres under it sufficient water to cover it to a depth of 1.65 feet, or an amount nearly equal to the rainfall in the State of Iowa from May 1 to September 30, 1899.

The Sebree Canal delivered 320 acre-feet daily. This volume would cover the 7,000 acres of land watered by it to a depth of 1.42 feet during the months of July and August. The canals and ditches on the first bottom delivered water at the rate of "1 inch to the acre," which would cover the land to a depth of 1.24 feet in thirty-one days.

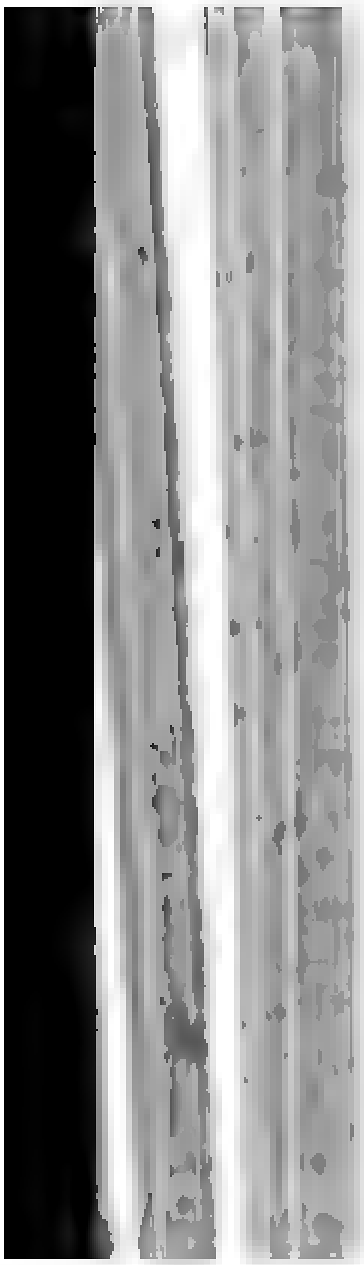
In some portions of the State the duty of water is nearly twice as great as in the Boise Valley. If the farmers of this valley are disposed to continue the present system, then the duty of water will remain low, the cost of water per acre high, and storage works for sufficient water to irrigate more than one-half the area lying below the present canals must be provided. If economical methods are inaugurated the cost of reservoirs to provide water for the irrigation of the remainder of the land will be proportionately decreased.

RELATION OF DUTY OF WATER TO THE FUTURE OF THE VALLEY.

Of the land embraced within the boundaries of irrigation canals constructed and projected in the Boise Valley, 88,440 acres have been acquired under the homestead act, 59,440 acres by purchase, 53,000 acres under the desert-land laws, 65,840 acres have been selected by the State of Idaho, and 133,080 acres are vacant public lands. Of these lands, 96,000 acres are waste, or above the level of canals, leaving 310,000 acres susceptible of irrigation. Of the 262,920 acres of land which have passed from the public domain, 184,859 acres have been patented. The assessed valuation of property in the Boise Valley made in April, 1891, exclusive of the value of canals, and three-fourths the value o[illegible] the city of Boise was $3,268,000, or a real



AM COMPARING THE QUANTITY OF WATER CLAIMED AND ACTUALLY DIVERTED BY THE PRINCIPAL CANALS IN THE BOISE VALLEY.



extended. This progress in the beneficial use of water is going on at the same time under the ditches last built and those first constructed. The benefits to the State from the labors of a settler under a new ditch are as great as from those who settled under the earlier ones, and it is simply a matter of chance which has the older citizenship. Where settlers come to the State the same year, file on land the same season, and use water in the same fashion, it is not easy to understand why they have not an equal right to the use of the State's public water supply, but there are some to whom this doctrine is heresy. The latter hold that the earlier ditches have exclusive rights and that to protect these there should be an immediate adjudication, having for its purpose the determination of which ditch should be allowed to increase its usefulness and which denied the privilege.

CONCLUSIONS.

The investigations which form the basis of this report show that a knowledge of the conditions which influence the duty of water is a fundamental necessity in the improvement of irrigation methods. The most effective method of promoting economy is to show the loss produced by waste. This is what the studies of the duty of water now being carried on by the United States Department of Agriculture are doing. The results of the first year's measurements in this valley show that fully one-half of the water now diverted by canals is wasted. It also shows that it is possible to reclaim more than twice the area of land now watered without any enlargement of the canals now in use. The surest way to bring this about is to have water contracts provide that canal companies shall measure the volume delivered and farmers pay for only what they receive.

INFLUENCE OF THE CHARACTER OF WATER-RIGHT CONTRACTS ON THE DUTY OF WATER.

(1) When farmers are charged for water according to the number of acres they irrigate, the temptation is to use the largest volume afforded them rather than the quantity needed.

(2) This system requires a constant flow, and when no rebate is given for the time water is shut off the tendency is to permit it to run continuously. The volume wasted is often a large percentage of the volume supplied. Waste robs the canal company directly and the farmer indirectly by reducing the productiveness of his farm.

(3) Were the charge for water based on the volume used, the loss from waste would be borne wholly by the irrigator, as it should be.

(4) A charge for the volume employed would result in a more beneficial use of water. A larger area could then be irrigated and revenues derived from the sale of water would increase.

(5) Under such administration the farmer would carefully prep the surface of his fields in order that the water might be applied the shortest possible time. He would endeavor to determine quantity of water actually required to produce the best results. Th an interest would be encouraged in the more accurate and scienti features of farming, which are always of incalculable benefit to eve community.

(6) The inauguration of a uniform system of rotation would tend increase the duty of water and proportionately reduce the cost irrigation. In order to properly carry this into effect, laterals boxes should always be in good condition.

(7) When this system is established, irrigation on each tract reduced to a routine, every farmer knowing in advance what si head of water he is entitled to and the length of time it will flow o his land. Under this plan he is also afforded an incentive to red the amount used by improving his methods of cultivation and distributing the water after it enters his fields.

(8) The company should construct a drainage system through the entire district connecting all swampy places with natural wa ways, and the water thus drained from the land should be under control for distribution.

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U. S. DEPARTMENT OF AGRICULTURE,

OFFICE OF EXPERIMENT STATIONS,

A. C. TRUE, Director.

RIGATION IN NEW JERSEY.

BY

EDWARD B. VOORHEES, M. A.,

Director New Jersey Agricultural Experiment Stations and Professor of Agriculture Rutgers College.

INGTON:

ING OFFICE.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., July 13, 1900.

Sir: I have the honor to transmit herewith and to recommend for publication as a bulletin of this Office a paper on Irrigation in New Jersey by Prof. Edward B. Voorhees, director of the New Jersey Agricultural Experiment Stations.

This bulletin has been prepared under the supervision of Mr. Elwood Mead, expert in charge of the irrigation investigations of this Office, and reports the results of experiments conducted for the purpose of determining whether irrigation during short periods of drought in regions where the rainfall is usually sufficient for the maximum growth of crops will sufficiently increase the yield to pay for the works necessary to obtain the supply of water.

So far as rainfall conditions are concerned, New Jersey belongs to the so-called humid region, and may be considered typical of the whole eastern half of the United States. Judging from the results reported in this bulletin, there seems to be no doubt that irrigation for fruits and market gardens, even in regions where rainfall is normally abundant, is a profitable undertaking. The work in New Jersey is a part of an investigation of the problems of irrigation now being carried on by the Office of Experiment Stations in different regions of the United States, the results of which have been partially reported in previous bulletins of this series.

Respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

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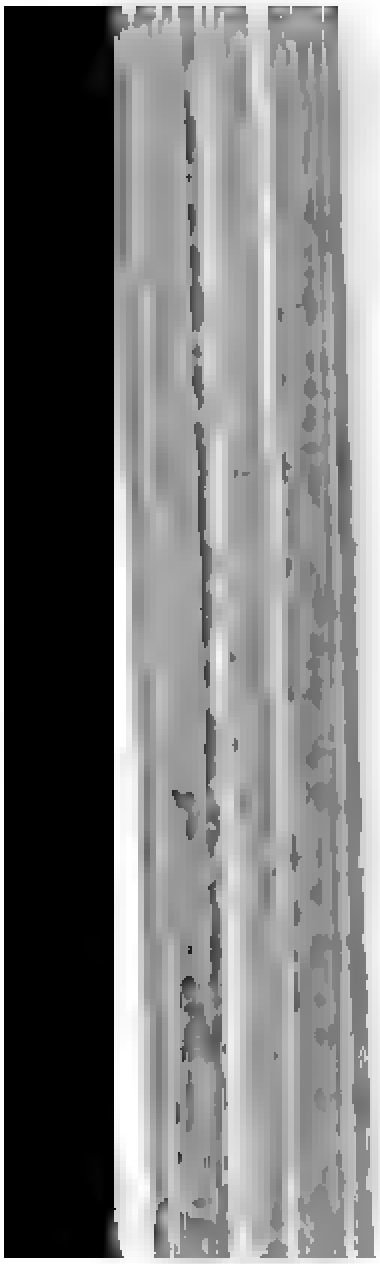

IRRIGATION IN NEW JERSEY.

INTRODUCTION.

Little importance has thus far been attached to the matter of irrigation in the Eastern States. This is due in large part to the fact that the rainfall is usually sufficient to meet the needs of vegetation and because serious or long protracted droughts are the exception rather than the rule. Owing, however, to the changes which have taken place in recent years in the character of the farming, attention has been aroused to the importance of controlling the moisture of soils rather than accepting the conditions as they exist, and a deficiency of rainfall for even a short period is now found to be more disastrous than the long periods of drought under old conditions of farm practice, though, even under extensive systems of farming, the losses from drought are often very serious. For example, in the season of 1899 it was so dry in May and early June that the yield of hay, an important crop in the East, was very light in New Jersey. The shortage in this crop amounted to more than one-half, which at a low estimate averaged $50 per farm, or a loss of more than $1,500,000 for the State. In the dairy regions the deficiency of rainfall also materially reduced the yield of the pasture and early forage crops, thus affecting the returns from this branch of farming. So seriously does a deficiency of rainfall affect the dairy interests that many progressive farmers now regularly plant a supplementary crop to provide sufficient forage in case of drought. It pays better to have an excess of forage, which may be wasted in part, in a good season, than to have a shortage. The deficiency of rainfall in 1899 also resulted in very serious injury to early crops, particularly asparagus, strawberries, and other berries; early beets and many other important early crops were also affected. It is perhaps not practicable, and it may not be possible, in many parts of the East to provide for the irrigation of the entire farm area. It is not known how far it would be practicable; hence it is eminently desirable that inquiry should be made concerning the question in the East and that experiments be carried out to determine whether a largely increased yield may be expected from irrigation, and thus show whether it is likely to prove a practicable and profitable undertaking.

SHORTAGE OF WATER IN HUMID REGIONS.

The fact that the conditions in the East are such as to make it seem that there is an abundance of water has also tended to obscure the real importance of the question—rains do come, and then the necessity and possible advantages of irrigation are lost sight of or forgotten until another drought occurs.

In New Jersey the need for irrigation is not apparent when the average annual rainfall is considered. This varies from 44.09 inches in the northwest to 49.7 inches on the seacoast, though the annual precipitation occasionally sinks as low as 31.05 inches in some localities, which is as low as the annual rainfall on the border of the subhumid regions of the West, and droughts during the growing months—April to August, inclusive—which result in a very considerable loss, occur more frequently than is popularly supposed. In other words, the average rainfall, while sufficient to meet the needs, if properly distributed, is found to be very unevenly distributed. Besides, much of the rain that falls during the summer months proves of little service, as the dashing showers, so common in summer, do not penetrate the soil as do the early spring and late fall rains, and a large proportion runs from the surface. Thus the statement of monthly rainfall, or even that during the growing season, is not a guide as to its efficiency unless accompanied by statements as to the character of the fall. In a large percentage of years there are one or two months during which the deficiency of rainfall is so serious as to cause a marked if not an entire loss of crop.

As an illustration of this point the following data from the Rutgers College farm records are interesting: In 1897 and 1898, years of abundant rainfall in April and May, the yield of hay averaged 2.65 tons per acre. In 1899 it was but a fraction over 1 ton, owing to the deficiency of rainfall in April and May—at the low price of $10 per ton, a loss for the 25 acres of over $400. The yield of crimson-clover forage for 1897 and 1898 was 8.5 tons per acre; in 1899 the yield was but 5 tons, or in a good year the yield was 70 per cent greater. The deficiency in the rainfall at the critical period was alone responsible for this difference in yield, as the catch was good and the land quite as fertile and as well prepared and fertilized as in the years of abundant rainfall. Oat and pea forage in 1897 and the early seeding of 1898 averaged 6 tons per acre; in 1899 the yield was but 3.3 tons. These figures from the carefully kept records of the farm show that a shortage of water at critical periods of growth does result in seriously reducing the returns that could reasonably be expected under favorable conditions.

The rainfall records in Philadelphia from 1825 to 1895 (70 years), for example, show that in 88 per cent of the years there was a deficiency of over 1 inch for one month, or that in 62 years out of the 70

there was one month in the growing season from April to August in which such a marked deficiency occurred as to cause a serious shortage of crop, and that for the same period there were 39 years in which the deficiency extended throughout two months, while in 21 years it extended throughout three months, or in 30 per cent of the years included in this record there were three months during the growing period in which the average rainfall was deficient 1 inch or more. It is thus observed that a wide series of crops would be likely to suffer in more than one-half of the years for which the record is available, while a still larger number would suffer in nearly one-third of the years, for it must be remembered that even a slight deficiency in one month may result in serious reduction in yield and consequent loss if it occurs at the time when the crop is making its largest development, as, for example, the grasses in May, and other forage crops in June or July or August; or when the crops are ripening, as berries in June or July; or in the case of the growth of vegetables, whose whole period of growth is included in one month.

AMOUNT OF WATER REQUIRED.

In making plans for irrigation, however, it is desirable to have definite data in reference to the water needed as a basis for calculation. As already pointed out, the average rainfall in New Jersey represents conditions very favorable to good crops, provided the distribution is relatively uniform throughout the growing season; hence the amount necessary for irrigation may be safely estimated to be the difference between the average and the minimum rainfall for the various periods. The lowest amount of rainfall from April to August, 1880 to 1895, inclusive, is found to be 9.33 inches, and by seasons the lowest for the spring, 5.23 inches, and for the summer, 4.62 inches.[1]

In the southern part of New Jersey, therefore, an equivalent of 12 inches of rainfall will be required for the whole growing season in certain years, and for certain months an equivalent of 4 inches will be required, in order that the deficiency may be met. The irrigation problem, so far as water requirements are concerned, is therefore a more complicated one in the East than in the arid regions, since in a certain number of years very little may be required, while in certain other years the maximum of 12 inches may be necessary. The capacity of irrigation works must be sufficient to meet the maximum requirements, though maximum demands will not be made, judging from past records, oftener than once in three years.

STORAGE OF WATER.

Investigations of the discharge of streams in southern New Jersey show that, with storage plants, an equivalent of 12 inches of rainfall

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 36.

the practicability of storage works is determined, for th
in this section of the State are favorable to a low cost
by means of canals and ditches, and it is estimated that
can be watered without the use of storage reservoirs at a
$8 per acre, not including the annual cost of applicatio
one-fifth of this, 15,000 acres, or even a much smaller
brought under irrigation in this way, it would enable th
of data which would help to determine whether the mor
storage plants would be likely to prove a financial success
gable area may also be largely increased without storage,
from wells. The areas thus available for irrigation are
under cultivation, and it is estimated that 175,000 acres c
gated in this way. Wells capable of providing 25,000
day, or sufficient water for an area of 10 acres, are fou
parts of southern New Jersey, yet, aside from this, it has
that there is enough water wasted annually to irrigate the
during the driest year, and, neglecting what may be water
fully 325,000 acres may be brought under water.[1]

CULTIVATION.

It is well for those who contemplate irrigation, however
ber that while water is the essential thing in times of droug
other conditions which should be considered quite as ca
no water is to be applied. That is, if the full duty of wa
attained, the land upon which it is to be applied should
prepared and measures taken to conserve not only natur
ficial supplies. The character of the soil and subsoil, the

encourage a slow penetration of water, with a maximum tendency to run off. In the former case preliminary preparation is not required and the application should be such as to gradually and continuously supply needs, while in the latter case the soil should be cultivated to full depth—subsoiled, if need be—and the surface particles made extremely fine, in order to encourage the percolation and absorption of the water, and after the application of water it should be cultivated frequently, in order to prevent the rapid escape of the water into the atmosphere. These are points well understood by the progressive farmer, but with an abundant supply of water the tendency would be to rely too much upon the artificial source of supply, and thus cause a waste. It is to be remembered, too, that water alone will not produce a crop; the land must be made fertile, and because of the larger crops consequent upon irrigation there will be a greater necessity for supplying fertilizers than if a crop fails through lack of water once in two or three years.

TIME OF APPLYING WATER.

Experience has shown that the best method of irrigation in the arid region is to give the land thorough soakings at considerable intervals of time. In that region the rainfall during the growing season is so small as not to enter into the calculations. In New Jersey, however, sudden showers, which result in a rainfall of from 2 to 3 inches, are not unusual. If these come immediately or soon after the application of 1 inch or more of water by irrigation, and the storm is followed, as frequently happens, by damp, muggy weather, the effect of the irrigation may be to decrease the crop rather than increase it, as excessive amounts of moisture under the conditions mentioned are conducive to the rapid spread of blights, diseases, rots, etc., which are likely to reduce the yield, and in many cases prove quite as disastrous as a deficiency of water. This is particularly true in the case of melons, potatoes, berries, etc.; it would not, of course, be the case with the cereals, the grasses, or the summer forage crops. In irrigating in this region it has been found to be a more prudent plan to use the water more frequently and in less amounts than is usual in the arid districts. This, while more expensive of time, obviates the danger here pointed out. It has been the practice here to begin the irrigation when the surface soil became dry and before the plants show any sign of suffering, and then to apply such an amount as will thoroughly moisten the soil and keep the crops growing. The dryness of the soil when necessary to begin, and its moisture when the irrigation should be stopped, are matters that can be learned from experience. The records of applications and the results obtained, on subsequent pages, show what the practice at the New Jersey Station is in the matter of application and the gains from the added water. In the object was to keep the soil moist, which term will be all

thoroughly soaked into the soil, the furrows are turned
whole cultivated.

EXPERIMENTS IN IRRIGATING SMALL FRUITS, 1896

The plan and scope of the work undertaken are fully ex
earlier bulletin of this office,* although a brief descriptio
here. The experiment ground contains 7 acres, separate
feet wide into three divisions, the higher ground in the
sion. The topography of the area shows a fall of 9.25 fe
highest to the lowest points, and that upon a large portio
there is a reasonable uniformity in the slope of the lan
mitting a ready and sufficiently rapid flow of water.
supplied by a 3-inch main, which runs through the mid
tees are placed every 75 feet, from which laterals, 1 inch
eter, are carried both north and south, ending in hydra
feet from the ground, and provided with faucets to whi
be attached for distributing the water. The fall from the
about 9 feet, thus affording a reasonably rapid flow from
and the supply is ample for the maximum demands for irr
poses.

The division lying on the south contains about 2 a
divided into four plats. The plats vary in size according
ber of varieties of crops included, as well as the distance
rows, though the irrigated and unirrigated plats for eac
variety are of the same size, and in all cases, with the row

The results published here were obtained from plants set in the spring of 1896, and include only blackberries, raspberries, gooseberries, and currants, as indicated, as the crops from the asparagus and from the other fruits have not yet been large enough to permit of a fair comparison. All the crops have been irrigated, the necessity for which is shown in the accompanying meteorological table:

Yearly precipitation on the experiment grounds for the years ended October 31, 1896, 1897, 1898, and 1899.

Year.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Total.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1896....	3.41	2.68	1.68	5.85	5.92	1.41	3.70	4.93	4.37	2.42	4.81	1.62	54.79
1897....	2.95	1.59	2.39	2.77	2.47	3.47	6.45	2.50	12.84	3.81	2.10	1.59	42.80
1898....	4.52	5.09	3.92	3.49	3.09	4.17	7.86	1.13	3.91	6.44	1.46	5.80	44.93
1899....	7.14	3.16	4.88	5.37	6.63	1.50	2.04	3.54	6.32	3.45	7.80	2.96	50.88

It will be observed that in each year there was one or more months in the growing season, April to August, in which there was a decided deficiency in rainfall—April and August in 1896, June in 1897, June in 1898, and April and May in 1899. The drought was very severe in 1898, and came at a time when blackberries especially were in greatest need of water.

The table given below shows the times of irrigation and the amounts of water applied during the four years for the different crops, and also a comparison of water applied and normal rainfall:

Date of application of water and amount used per plat.

BLACKBERRIES.

Year.	Date of application.	Amount applied.	Equal to inches of rainfall.	Rainfall.	Rainfall plus irrigation.	Normal rainfall.
		Gallons.		*Inches.*	*Inches.*	*Inches.*
1896	May 16	825	0.79			
	June 8	1,096	1.06			
	Total	1,921	1.85	5.11	6.96	7.54
1897	June 21	500	.47			
	June 29	480	.46			
	July 8	350	.33			
	Total	1,330	1.26	2.50	3.76	3.05
1898	June 25	800	.62			
	June 30	450	.45			
	July 5	1,035	1.00			
	July 9	450	.45			
	July 16	200	.21			
	July 26	225	.23			
	Total	3,160	2.96	5.04	8.00	7.33
1899	May 26	500	.47			
	June 3	1,023	.98			
	Total	1,523	1.45	5.58	7.03	7.23

ILLUSTRATIONS.

shown by a comparison of the yie[illegible] irrigated plats were large, sweet, and succulent, while unirrigated were small, sour, and hard. The only eviden[illegible] in the case of the blackberries was the fact that they w[illegible]

BLACKBERRIES.

The following table of yields of blackberries in 1898 [illegible] that different varieties of this fruit differ widely in refe[illegible] drought-resisting power, and consequently in the benefi[illegible] derived from irrigation. Since only plats 1 and 2 repre[illegible] be regarded as good conditions of manuring, the yields [illegible] only are considered:

Yields of blackberries per acre on irrigated and unirrigated plats, 18[illegible]

Variety.	1898.	
	Plat 1	Plat 2
	Quarts.	*Quarts.*
Early Harvest		
Irrigated	5,070	2,705
Unirrigated	4,069	2,409
Gain from irrigation	1,001	296
Wilson Jr		
Irrigated	2,665	3,344
Unirrigated	409	1,735
Gain from irrigation	2,256	1,609
Erie		
Irrigated	2,847	1,196
Unirrigated	2,808	3,360
Gain from irrigation	39	−2,164

A study of the yields in 1898 shows a wide range on both the unirrigated and irrigated land for the different varieties. On the unirrigated the lowest yield is 409 quarts for Wilson Jr., and the highest 4,026 quarts for Eldorado, while on the irrigated plats the lowest yield is 2,385 quarts for Agawam, and the highest 7,985 quarts for the Eldorado. On plat 2 the lowest yield, unirrigated, is 204 quarts for Eldorado, and the highest 3,360 quarts for the Erie, while on the irrigated the lowest yield is 1,196 quarts for the Erie and the highest 3,344 quarts for Wilson Jr. A very wide variation in the yield of the unirrigated, as well as the irrigated, is due to the variety of the berry, and is in part caused by the difference in time of ripening. The date of the first picking of th[illegible]fferent varieties is as follows:

Variety.	1898.	1899.
Early Harvest	July 4	June 30.
Wilson Jr	July 8	July 8.
Eldorado	July 14	Do.
Erie	....do	July 12.
Agawam	July 16	July 10.
Taylor	July 19	July 15.

Out of the 24 possible com[illegible]sons, however, 23 show an effect from irrigation, and in 14 cases o[illegible] the 24 the irrigation has resulted in an increase in yield of over [illegible] per cent. In 1899 the lowest yield on the unirrigated plat No. 1 wa[illegible]0 quarts for the Erie, and the highest 1,722 quarts for the Agawam, while the lowest yield from the irrigated is 2,561 quarts for the Tay[illegible]r, and the highest 6,571 quarts for the Eldorado. The difference o[illegible]rved in the varieties for the two years is undoubtedly due in part t[illegible] different period in which the drought existed. Taking the averag[illegible] the yield of all the plats, the unirrigated was 1,690 quarts and the irrigated was 3,327 quarts per acre, or a gain from irrigation for all varieties for the two years of 1,637 quarts per acre, or 97 per cent, a gain in quarts larger than that obtained as the average yield of the State. It thus seems to be not only a question of berries, but a question of the variety as well. This is not a place to discuss the relative advantages of different varieties of blackberries, still the striking differences in yields, both under natural and artificial conditions in reference to water supply, show the importance of a study of this point.

A study of the preceding table shows very clearly the effectiveness of irrigation for this fruit. A decided benefit is shown in 75 per cent of the cases in which a comparison of varieties and methods of treatment is possible; in other words, it is demonstrated that it is not a question of particularly good circumstances, as the conditions as to variety and method of fertilization are widely variable. To bring out the points more clearly, and to show what may be expected under average conditions of treatment, a table has been prepared which shows the

average yields of all of the plats, irrigated and unirrigated, for each variety for 1898 and 1899, as well as the average yields for the two successive years:

Average yields of blackberries per acre on all the plats, 1898 and 1899.

Variety.	Irrigated.	Unirrigated.	Gain from irrigation.	
	Quarts.	*Quarts.*	*Quarts*	*Per cent.*
Early Harvest:				
1898	2,805	2,404	401	16.6
1899	2,607	1,443	1,164	80.7
1898-99	2,706	1,923	783	40.5
Wilson Jr.:				
1898	2,182	1,624	558	34.4
1899	2,164	1,275	889	70.0
1898-99	2,173	1,449	724	50.0
Erie:				
1898	1,437	3,418	....	....
1899	2,693	1,542	1,151	74.6
1898-99	2,065	2,480	....	....
Agawam:				
1898	4,218	2,461	1,757	71.4
1899	4,935	3,293	1,642	50.0
1898-99	4,576	2,877	1,699	59.0
Taylor:				
1898	2,497	661	1,836	277.0
1899	2,148	1,995	153	8.0
1898-99	2,323	1,328	995	74.9
Eldorado:				
1898	3,026	1,201	1,825	152.0
1899	4,911	1,848	3,063	165.0
1898-99	3,969	1,525	2,444	160.0

It will be observed that there is a gain from irrigation in the case of every variety except the Erie, and that in the majority of cases irrigation has resulted in largely increased yields. Excluding the Erie, the average gain for the two years ranges from 724 to 2,444 quarts per acre. The larger figure represents a fairly high yield in itself, and shows that the best returns are obtained with the best variety. The value of irrigation is, however, not measured by yield alone, for it is a well-known fact that, notwithstanding the present facilities for the distribution of fruits, a serious shortage in the yield of such a perishable product as berries in any one State, or in the section of a State in which the crop is an important one, has its influence upon the price received per quart, particularly in the smaller towns, so that the gain due to irrigation is influenced by the enhanced price received; that is, the average price in a season of abundant rainfall is not a guide as to the prices that may prevail in a season of shortage. This consideration is a most important one, so long as irrigation is confined to limited areas. In 1898 the wholesale price of blackberries was 10 cents per quart; that is, buyers were anxious to get them at that price, owing to the shortage of the crop in the State, due to the drought

preceding their ripening, which practically ruined the crop in many sections of the East. In 1899 the shortage was not so serious; nevertheless they were readily sold at 8 cents per quart, making an average for the two years of 9 cents per quart, or a wholesale price 2 cents per quart above what is regarded as fairly remunerative.

On the basis of this average price the increased value per acre of the berries on the irrigated plats ranged from $65.16 for Wilson Jr., to $219.96 for Eldorado; or, averaging all of the varieties for both years, we have a gain from irrigation of 53.8 per cent, or 1,038 quarts per acre, worth $93.42.

The statistics gathered by the New Jersey Station in 1895 concerning the growth of blackberries showed that upon the clay loam soils the average yield per acre for 1893 and 1894 was 1,300 quarts, and that upon the sandy soils the average yield for the same period was 834 quarts per acre. The soil of the experiment ground is a clay loam and may be safely regarded as representative of the average for the State. Applying the average percentage gain obtained on all the varieties by irrigation for the two years 1898 and 1899 to the average yield of the State, we have an increase of 699 quarts per acre, worth $62.91. In the case of the sandy soils the results from irrigation would doubtless be more striking than in the case of the clay loams, since while the crop might not suffer any sooner, the greater capacity of such soils to absorb heat would cause a more rapid drying of the berries; still, with the same increase from irrigation the gain would be 449 quarts per acre, worth $40.41. The yields here quoted are the average, and do not represent even good conditions of soil and management, as many growers believe that the berries are better adapted for the poorer light soils than for the heavier and more fertile ones. The application of the percentage increase from irrigation does not, therefore, fully show the possible advantages to be derived. The maximum yield reported for New Jersey was 8,000 quarts, which doubtless represents the best conditions as to soil, season, and variety, since it corresponds to that obtained on the irrigated plat in 1898, viz, 7,985 quarts. In New York State the average yield reported is 3,158 quarts, with a maximum of 10,000 quarts.

Assuming that the average yield in New York could be increased 53.8 per cent by irrigation, the gain per acre would be 1,700 quarts, worth $153. That this gain is quite possible is also clearly shown by the report, which indicates that under best conditions the yield may reach 10,000 quarts. Assuming that the necessity for irrigation is apparent only once in two years, and the average yield under average conditions of treatment without irrigation is 1,500 quarts per acre for the two States, the gain would be 403½ quarts per year, which at 9 cents per quart is $36.32, or equivalent to an interest of 6 per cent on an outlay of $600 per acre, which is more per year than the cost of

irrigation work planned on a large scale, or more than the total cost of small plants capable of irrigating 6 to 8 acres. This would seem to be a fair statement, and applies to average rather than good conditions of manuring and cultivation. This return would be sufficient the first year to pay much more than the full cost, and the surplus may be applied to the extra cost of growing the crop under irrigation. It is recognized that the growing of blackberries is not a large industry, still the statistical reports for New Jersey in 1895 showed an area of 2,850 acres, distributed in areas of from 1 to 4 acres, and chiefly located in sections of the State where irrigation could be practiced. Even if only one-quarter of the total area is capable of irrigation, and assuming the low average yields now obtained, the gain from irrigation on this basis would mean an addition of over $25,000 to the net returns of the grower.

RASPBERRIES.

The following table shows the yields of raspberries for the years 1898 and 1899 on irrigated and unirrigated plats:

Total yields of raspberries per acre on irrigated and unirrigated plats, 1898 and 1899.

Variety	1898.		1899.	
	Plat 1.	Plat 2.	Plat 1.	Plat 2.
Cuthbert	*Quarts.*	*Quarts.*	*Quarts.*	*Quarts.*
Irrigated	4,072	1,485	4,702	[illegible]
Unirrigated	2,655	1,062	3,979	[illegible]
Gain from irrigation	1,417	423	723	[illegible]
Marlboro				
Irrigated	2,556	562	2,138	[illegible]
Unirrigated	1,251	369	1,732	[illegible]
Gain from irrigation	1,305	193	406	[illegible]
Turner				
Irrigated	1,593	733	2,009	[illegible]
Unirrigated	778	886	2,653	[illegible]
Gain from irrigation	815	−153	−644	[illegible]

Comparing plats 1 and 2, as in the case of the blackberries, it is observed that in 1898 in five cases out of the six there is a gain in yield from irrigation, and that the differences due to the variety are quite as marked as in the case of the blackberries. The lowest yield on plat 1, unirrigated, is for Turner, 778 quarts, and the highest, 2,655 quarts, for Cuthbert, while the lowest from the irrigated on the same plat is 1,593 quarts, for Turner, and the highest 4,072 quarts, for Cuthbert. The lowest yield on plat 2, unirrigated, is 369 quarts, for Marlboro, and the highest is 1,062 quarts, for Cuthbert, while the lowest from the irrigated plat is 562 quarts, for Marlboro, and the highest is 1,485 quarts, for Cuthbert. In 1899 irrigation was effective in four out of the six cases, though in no case was the advantage from irrigation as great as in 1898, nor were the variations in yield as marked as in

that year. The average gain from irrigation for the two years was 618 quarts per acre, or 20 per cent.

The following table shows the average yields for all the plats, and the actual and percentage gain from irrigation:

Average yields of raspberries per acre on all the plats for 1898 and 1899.

Variety.	Irrigated.	Unirrigated.	Gain from irrigation.	
	Quarts.	*Quarts.*	*Quarts.*	*Per cent.*
Cuthbert:				
1898	2,076	1,472	604	41.0
1899	4,593	4,261	332	7.7
1898–99	3,335	2,866	468	16.3
Marlboro:				
1898	1,065	624	441	70.7
1899	2,311	1,509	802	53.1
1898–99	1,688	1,067	621	58.2
Turner:				
1898	837	754	83	10.9
1899	1,457	1,744	−287	....
1898–99	1,147	1,249	−102	....

With the exception of one variety one year (Turner in 1899), there is an increased average yield from irrigation of all the varieties for the two years, ranging from 468 to 621 quarts, which, at 10 cents per quart, shows a gain of from $46.80 to $62.10 per acre. Including the Turner, the average gain for all is reduced to 19 per cent, making 329 quarts, worth $32.90 per acre.

The statistics as to yields show that the average for New Jersey is 1,928 quarts, and for New York 2,201 quarts per acre, with a maximum of 6,000 in the former and 8,000 quarts in the latter. It is to be fairly assumed that the lower average yield is a result in part of the lack of sufficient moisture, inasmuch as the average for these States is slightly higher than the average of the unirrigated plats for 1898 and 1899. Hence, the average percentage increase as shown by the experiments may be safely applied to the average yields of these States, as showing the possible gain from irrigation in years of serious shortage of water. In the case of New Jersey the increased yield represents a value of $36.63 per acre, and in New York, $41.82 per acre. Assuming, as in the case of the blackberries, that the need for irrigation is not apparent annually, but only once in two years, we have an average per year of $18.31 for New Jersey, and $20.91 for New York, considerably lower than in the case of blackberries, yet a sum in excess of that needed to provide for irrigation by permanent storage works. As a business proposition, even the irrigation of raspberries alone is worthy of consideration. The area of red raspberries in New Jersey is 1,052 acres, and in New York the area is considerably larger, owing to the ve[illegible]g industry there.

It was not possible to include a study of the effect of irrigation on blackcap berries, as the conditions at the experiment grounds were not favorable for this fruit. The area of blackcaps in the State, however, is quite as large as that for the red, and in New York it is considerably larger than for the red. Neither is there any good reason to doubt but that irrigation would have been quite as effective.

CURRANTS.

The yields of currants on irrigated and unirrigated plats for 1898 and 1899 were as follows:

Total yields of currants per acre on irrigated and unirrigated plats, 1898 and 1899.

Variety.	1898.		1899.	
	Plat 1.	Plat 2.	Plat 1.	Plat 2.
Fay Prolific:	*Quarts.*	*Quarts.*	*Quarts.*	*Quarts.*
Irrigated	66	24	1,464	624
Unirrigated	36	84	396	2,340
Gain from irrigation	30	−60	1,068	−1,716
Red Dutch:				
Irrigated	1,194	960	3,264	4,644
Unirrigated	768	192	3,252	1,692
Gain from irrigation	426	768	12	2,952
Victoria:				
Irrigated	1,560	756	4,176	3,072
Unirrigated	1,248	300	3,228	2,472
Gain from irrigation	312	456	948	600
White Grape:				
Irrigated	606	420	1,044	1,560
Unirrigated	492	72	1,032	696
Gain from irrigation	114	348	12	864

Marked differences are also shown in reference to the yields of the different varieties, though in 14 out of the 16 a very decided gain is observed from irrigation. The yield in the case of Fay Prolific was very low in 1898, so that a comparison on the percentage basis would mean but very little; still, for the two years the gain from irrigation is 496 quarts, or a gain of over 43 per cent.

The results of the irrigation on currants are less satisfactory in one sense than upon blackberries and raspberries, owing to the fact that the plants have not yet reached maturity, and therefore the yields are relatively low; still, the percentage of increase in yield due to irrigation is applicable to the averages obtained in the State.

The results published here were obtained from plants set in the spring of 1896, and include only blackberries, raspberries, gooseberries, and currants, as indicated, as the crops from the asparagus and from the other fruits have not yet been large enough to permit of a fair comparison. All the crops have been irrigated, the necessity for which is shown in the accompanying meteorological table:

Yearly precipitation on the experiment grounds for the years ended October 31, 1896, 1897, 1898, and 1899.

Year.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Total.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
1896....	3.41	2.68	1.68	5.85	5.92	1.41	3.70	4.93	4.37	2.42	4.81	1.62	54.79
1897....	2.95	1.59	2.39	2.77	2.47	3.47	6.45	2.50	12.84	3.81	2.10	1.59	42.80
1898....	4.52	5.09	3.92	3.49	3.09	4.17	7.86	1.13	3.91	6.44	1.46	5.80	44.93
1899....	7.14	3.16	4.88	5.37	6.63	1.50	2.04	3.54	6.32	3.45	7.80	2.96	50.88

It will be observed that in each year there was one or more months in the growing season, April to August, in which there was a decided deficiency in rainfall—April and August in 1896, June in 1897, June in 1898, and April and May in 1899. The drought was very severe in 1898, and came at a time when blackberries especially were in greatest need of water.

The table given below shows the times of irrigation and the amounts of water applied during the four years for the different crops, and also a comparison of water applied and normal rainfall:

Date of application of water and amount used per plat.

BLACKBERRIES.

Year.	Date of application.	Amount applied.	Equal to inches of rainfall.	Rainfall.	Rainfall plus irrigation.	Normal rainfall.
		Gallons.		*Inches.*	*Inches.*	*Inches.*
1896	May 16	825	0.79	....	....	....
	June 8	1,096	1.06	....	....	....
	Total	1,921	1.85	5.11	6.96	7.54
1897	June 21	500	.47	....	....	....
	June 29	480	.46	....	....	....
	July 8	350	.33	....	....	....
	Total	1,330	1.26	2.50	3.76	3.05
1898	June 25	800	.62	....	....	....
	June 30	450	.45	....	....	....
	July 5	1,035	1.00	....	....	....
	July 9	450	.45	....	....	....
	July 16	200	.21	....	....	....
	July 26	225	.23	....	....	....
	Total	3,160	2.96	5.04	8.00	7.33
1899	May 26	500	.47	....	....	....
	June 3	1,023	.98	....	....	....
	Total	1,523	1.45	5.58	7.03	7.23

Date of application of water and amount used per plat—Continued.

RASPBERRIES.

Year	Date of application.	Amount applied.	Equal to inches of rainfall.	Rainfall.	Rainfall plus irrigation.	Normal rainfall.
		Gallons.		*Inches.*	*Inches.*	*Inches.*
1896	May 15	840	1.11			
	June 6	1,200	1.66			
	Total	2,040	2.[illegible]	5.11	7.[illegible]	7.54
1897	June 19	680	.90			
	June 28	502	.66			
	July 19	450	.60			
	Total	1,632	2.16	2.50	4.66	3.66
1898	June 21	810	1.08			
	June 29	450	.60			
	July 6	540	.72			
	July 8	540	.72			
	Total	2,340	3.12	5.04	8.17	7.22
1899	May 29	715	.94			
	July 8	715	.94			
	Total	1,430	1.88	5.58	7.46	7.22

GOOSEBERRIES.

Year	Date of application.	Amount applied.	Equal to inches of rainfall.	Rainfall.	Rainfall plus irrigation.	Normal rainfall.
1896	May 13	210	.52			
	June 8	245	.60			
	Total	455	1.12	5.11	6.23	7.54
1897	June 18	180	.47			
	July 9	300	.78			
	Total	480	1.25	2.50	3.75	3.66
1898	June 23	450	1.17			
	July 2	330	.88			
	July 11	270	.71			
	Total	1,050	2.76	5.04	7.80	7.22
1899	June 1	310	.79	5.58	6.37	7.22

CURRANTS.

Year	Date of application.	Amount applied.	Equal to inches of rainfall.	Rainfall.	Rainfall plus irrigation.	Normal rainfall.
1896	May 13	300	.78			
	June 8	210	.52			
	Total	510	1.30	5.11	6.41	7.54
1897	June 18	210	.52			
	July 9	300	.78			
	Total	510	1.30	2.50	3.80	3.66
1898	June 21	300	.78			
	July 2	270	.71			
	July 11	270	.71			
	Total	840	2.20	5.04	7.24	7.22
1899	June 1	310	.79	5.58	6.37	7.22

The four plats in the case of any one variety differ only in the kinds of fertilizer applied. Plat 1 received yard manure at the rate of 20 tons per acre; plat 2, a complete fertilizer containing 4.5 per cent nitrogen, 7.7 per cent phosphoric acid, and 13.3 per cent potash; plat 3 received 300 pounds per acre of an even mixture of

and muriate of potash: plat 4 received 300 pounds per acre of an even mixture of ground bone and potash, and 200 pounds of nitrate of soda per acre. Plats 1 and 2, therefore, may be regarded as having been supplied with an abundance of all of the constituents and in such forms as to supply the entire needs of the plants. The larger yield on the manured plat for 1898 is due to the fact that nearly every plant grew, while on the other plats many died during the summer of 1896, hence the greater age and vigor of the plants encouraged the larger yield that year. The comparison as to irrigation is, however, not affected. With the exception of 1897 the total rainfall was fully up to the normal, yet in the region of the State in which the station is located the normal rainfall is usually sufficient to perfectly mature crops. While during a drought the atmospheric and temperature conditions are usually such as to cause a more rapid drying than would be the case with frequent light rainfalls and a larger proportion of cloudy days, the amounts applied were adjusted as nearly as it was possible to do so, in order to provide an equivalent to a normal rainfall, taking into consideration the relatively more rapid evaporation of water from the surface due to a greater proportion of sunshine. The results obtained also clearly demonstrate that it is not possible to closely approximate the influence upon growth and development of the kind of crops under experiment of an excessive rainfall during a month previous to the one of great deficiency, though care was taken by means of frequent cultivation to conserve the excess of that month. In 1898, for example, the excess over the normal for May was more than sufficient to meet the deficiency in both June and July, yet notwithstanding this excess the deficiency in those months caused a very serious injury to the crops, as shown by the yield on the unirrigated plats. The influence of the excess in May was not marked and an application of water during June and July, equivalent to 3 inches of rainfall, caused a decided increase in crop.

The most serious deficiency in rainfall for these crops occurs in one month, and the first application was made usually before the plants really suffered, but when it was known that a deficiency existed without special testing of the soil. Owing to the character of the plants no water was applied when a marked deviation from the normal rainfall occurred after the crops were harvested, as was the case in the month of September, 1897, and 1898. Naturally, in 1896, the season in which the plants were set, the effect of the added water could not be measured, neither could it be measured with any degree of accuracy in 1897, as the crops were still very small. The effect, if any, of the ...lded water in those years can be shown only by a comparison of the ...ds in 1898 and 1899. It will be observed from the table that in ... the crops the amount of water applied was prac... the deficiency in rainfall, and naturally the

All plats were cultivated seven times and hoed once. They were irrigated three times.

Irrigation was not needed so often on plats receiving stable manure. The nitrate of soda was applied broadcast in three equal applications—April 12, May 6, and June 3.

Before irrigation the plats fertilized with stable manure were ahead of those supplied with chemical fertilizer. On May 17 they had been badly eaten with worms. On June 8 the unirrigated cabbage wilted in the middle of the day, and some of the leaves were turning yellow.

The yields were as follows:

Yields of cabbage.

	Before July 10.	Total.
	Pounds.	*Pounds.*
Plat 1	214	[1] 609
Plat 2	271	[1] 639
Plat 3	139	564
Plat 4	173	632
Plat 5	184	[1] 621
Plat 6	200	[1] 614
Plat 7	125	528
Plat 8	127	664

[1] Irrigated.

A study of the yields shows that nitrate of soda affected favorably the earliness of the cabbage, and had a greater effect when used in connection with irrigation than without. Nitrate of soda with barnyard manure, in connection with irrigation, gave the best results. The total yields do not show decisive results of treatment. The rains that fell as the cabbage was maturing had a very beneficial effect.

An examination of the table shows that in every case irrigation promoted earliness of maturity. This was very important in 1899, since cabbage sold before July 10 at prices that netted from \$1.65 to \$1 per barrel of about 95 pounds. After July 10 they netted from 55 cents to 20 cents per barrel. The amounts received, net, from the different plats were as follows:

Amounts received per plat for cabbage.

Plat 1	\$5.10	Plat 5	\$4.82
Plat 2	5.45	Plat 6	4.83
Plat 3	3.82	Plat 7	3.10
Plat 4	4.53	Plat 8	3.94

Plats 1, 2, 5, and 6 constitute one-quarter of an acre of irrigated cabbage; plats 3, 4, 7, and 8, one-quarter of an acre of unirrigated. The two differ only as regards irrigation. The net income from the irrigated quarter acre was \$20.20, or \$80.80 per acre; from the unirrigated, \$15.39, or \$61.56 per acre. The cost of irrigating 1 acre of cabbage three times was approximately \$2.50. The capacity of the plant was sufficient to irrigate 20 to 30 acres of cabbage; thus the profit

A study of the yields in 1898 shows a wide range on both the unirrigated and irrigated land for the different varieties. On the unirrigated the lowest yield is 409 quarts for Wilson Jr., and the highest 4,026 quarts for Eldorado, while on the irrigated plats the lowest yield is 2,385 quarts for Agawam, and the highest 7,985 quarts for the Eldorado. On plat 2 the lowest yield, unirrigated, is 204 quarts for Eldorado, and the highest 3,360 quarts for the Erie, while on the irrigated the lowest yield is 1,196 quarts for the Erie and the highest 3,344 quarts for Wilson Jr. A very wide variation in the yield of the unirrigated, as well as the irrigated, is due to the variety of the berry, and is in part caused by the difference in time of ripening. The date of the first picking of t[illegible]fferent varieties is as follows:

Variety.	1898.	1899.
Early Harvest	July 4	June 30.
Wilson Jr.	July 8	July 8.
Eldorado	July 14	Do.
Erie	....do ..	July 12.
Agawam	July 16	July 10.
Taylor	July 19	July 15.

Out of the 24 possible co[illegible]sons, however, 23 show an effect from irrigation, and in 14 cases [illegible] the 24 the irrigation has resulted in an increase in yield of over [illegible]er cent. In 1899 the lowest yield on the unirrigated plat No. 1 w[illegible]0 quarts for the Erie, and the highest 1,722 quarts for the Agawam[illegible]ile the lowest yield from the irrigated is 2,561 quarts for the Tay[illegible], and the highest 6,571 quarts for the Eldorado. The difference [illegible]ved in the varieties for the two years is undoubtedly due in part t[illegible] different period in which the drought existed. Taking the averag[illegible] the yield of all the plats, the unirrigated was 1,690 quarts and the irrigated was 3,327 quarts per acre, or a gain from irrigation for all varieties for the two years of 1,637 quarts per acre, or 97 per[illegible]t, a gain in quarts larger than that obtained as the average yi[illegible]f the State. It thus seems to be not only a question of berries, but a question of the variety as well. This is not a place to discuss the relative advantages of different varieties of blackberries, still the striking differences in yields, both under natural and artificial conditions in reference to water supply, show the importance of a study of this point.

A study of the preceding table shows very clearly the effectiveness of irrigation for this fruit. A decided benefit is shown in 75 per cent of the cases in which a comparison of varieties and methods of treatment is possible; in other words, it is demonstrated that it is not a question of particularly good circumstances, as the conditions as to variety and method of fertilization are widely variable. To bring out the points more clearly, and to show what may be expected under average [illegible]atment, a table has been prepared which shows the

of the sweet potatoes the estimates are made from net receipts from the New York market at time of harvesting.

Tomatoes were worth from 15 to 20 cents per basket during the early season, and 5 cents per basket later. The profit from irrigation amounted to about $18 per acre.

The price of watermelons was higher at the first picking, but it held up fairly well until the last two pickings, when the vines had blighted and injured the quality of a part of the melons. Leaving out of account the last two pickings, the yields of the two plats were: Irrigated, 38 melons, weighing 713 pounds; unirrigated, 27 melons, weighing 495 pounds. A 25-pound melon was worth 15 to 20 cents early, and 10 cents during the greater part of the season. On this basis the profit from irrigation would amount to about $25 per acre.

The effect of irrigation on sweet potatoes was very noticeable. September 4 40 hills were dug from each plat; 62 pounds "prime" and 30 pounds "seconds" were secured from the irrigated plat; 35 pounds "prime" and 30 pounds "seconds" from the unirrigated plat, or a gain of 77.1 per cent of "primes." September 6 the same number of hills were dug into and the large potatoes removed, leaving the hill undisturbed, as far as possible. One hundred pounds were taken from the irrigated and 53 pounds from the unirrigated, a gain of 88.7 per cent. Immediately after this the sweet potatoes were thoroughly irrigated. The object of this test was to ascertain if some potatoes could be withdrawn early and then by thorough irrigation the small potatoes be made to grow into "primes" by the usual digging time. The results would indicate that this could be done. The price at the various digging times was $1.50 per barrel, primes, net, and 80 cents for seconds, and 25 cents for thirds. Before September 4 the price was considerably higher, and some could have been dug earlier, especially from the irrigated plat. The profit accruing from irrigation was $43.68 per ace. The expense of irrigating sweet potatoes would be about the same as for early cabbage.

It will be noticed that irrigation was injurious to sowed corn and cucumbers in these experiments.

CONSTRUCTION AND COST OF SMALL IRRIGATION PLANTS.

The irrigation practiced in the East thus far has been on a small scale. Plants capable of irrigating 6 to 8 acres are the rule. In the following pages several small plants recently installed are described in detail as to construction and cost, in order that those interested may determine from the data given whether under their conditions the installation of plants will prove profitable investments.[1]

[1] For descripton of other irrigation plants in New Jersey, see U. S. Dept. Agr., Office of Experiment Stations Bul. 35.

PLANT OF GEORGE A. MITCHELL, VINELAND, N. J.

The irrigation works of George A. Mitchell consisted originally of a 2.5-horsepower gasoline engine, a single-acting force pump and delivery pipe, consisting of a 2.5-inch wrought-iron pipe, and condemned fire hose, and homemade distributing hose of tarred duck cloth. The engine and pump were inclosed in a building near the bank of a creek, a ditch leading the water to the pump. The water was then pumped 693 feet to the highest point on the farm, whence it was carried to different locations in the same manner as is now done. From 40 to 60 gallons per minute were pumped.

Figure 1 shows the shape, surroundings, location of pumping plant, and topography, etc., of the farm.

The slopes from the 20-foot elevation to the creek and south to Elmer road are comparatively regular, being steepest for about 150 feet each side of the highest point.

In the spring of 1899 the engine and engine house were moved farther away from the creek, and a ditch 15 rods long by 2½ feet wide was dug

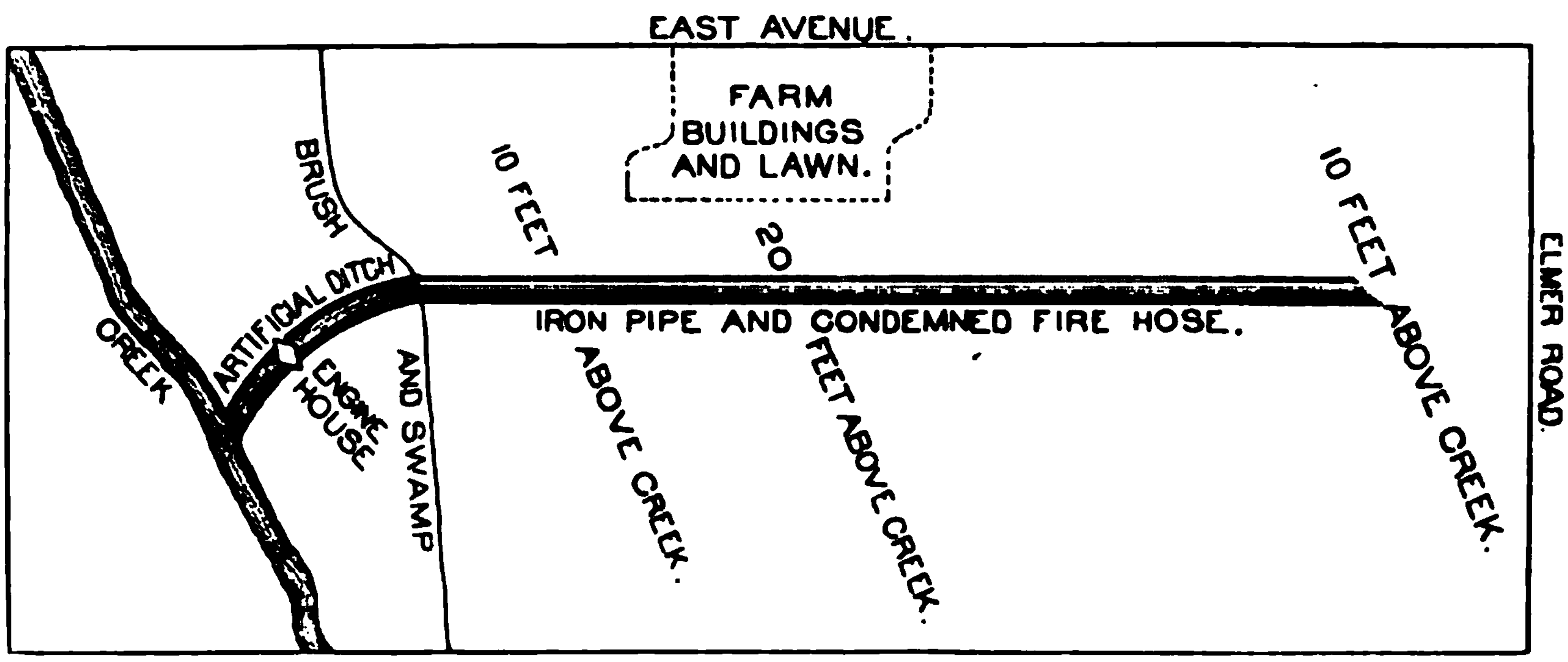

FIG. 1.—Irrigation plant of George A. Mitchell.

to bring the water to the pump. The water in the creek is raised 6 to 12 inches by a dam. A No. 2 centrifugal pump was secured with a 10-inch pulley, and set 10 feet center to center of pulleys from engine. The 3-inch leather belting runs from 2½-foot fly wheel of engine to pulley on pump. The engine makes 320 revolutions per minute.

An 18-foot length of 3-inch pipe is fastened to the pump outlet by means of reducers, and is held in a perpendicular position by four guy wires. An elbow with a 2-foot length of pipe is fastened to the top of the upright or standpipe. The hose is fastened to this by binding with wire. The hose used is of the home-made kind hereafter described, and is 7½ inches in diameter. The different lengths are connected by inserting a short length of stovepipe into the two ends and binding the hose to the pipe with wire. The large hose is used as the main, and extends 425 feet from the standpipe to the highest point on the farm. The hose is supported on a trestlework, which slopes 4 feet

irrigation work planned on a large scale, or more than the total cost of small plants capable of irrigating 6 to 8 acres. This would seem to be a fair statement, and applies to average rather than good conditions of manuring and cultivation. This return would be sufficient the first year to pay much more than the full cost, and the surplus may be applied to the extra cost of growing the crop under irrigation. It is recognized that the growing of blackberries is not a large industry, still the statistical reports for New Jersey in 1895 showed an area of 2,850 acres, distributed in areas of from 1 to 4 acres, and chiefly located in sections of the State where irrigation could be practiced. Even if only one-quarter of the total area is capable of irrigation, and assuming the low average yields now obtained, the gain from irrigation on this basis would mean an addition of over $25,000 to the net returns of the grower.

RASPBERRIES.

The following table shows the yields of raspberries for the years 1898 and 1899 on irrigated and unirrigated plats:

Total yields of raspberries per acre on irrigated and unirrigated plats, 1898 and 1899.

Variety.	1898.		1899.	
	Plat 1.	Plat 2.	Plat 1.	Plat 2.
Cuthbert:	*Quarts.*	*Quarts.*	*Quarts.*	*Quarts.*
Irrigated	4,072	1,485	4,702	4,573
Unirrigated	2,655	1,062	3,979	4,227
Gain from irrigation	1,417	423	723	346
Marlboro:				
Irrigated	2,556	562	2,138	2,217
Unirrigated	1,251	369	1,732	1,732
Gain from irrigation	1,305	193	406	485
Turner:				
Irrigated	1,593	733	2,009	1,762
Unirrigated	778	886	2,653	2,138
Gain from irrigation	815	−153	−644	-376

Comparing plats 1 and 2, as in the case of the blackberries, it is observed that in 1898 in five cases out of the six there is a gain in yield from irrigation, and that the differences due to the variety are quite as marked as in the case of the blackberries. The lowest yield on plat 1, unirrigated, is for Turner, 778 quarts, and the highest, 2,655 quarts, for Cuthbert, while the lowest from the irrigated on the same plat is 1,593 quarts, for Turner, and the highest 4,072 quarts, for Cuthbert. The lowest yield on plat 2, unirrigated, is 369 quarts, for Marlboro, and the highest is 1,062 quarts, for Cuthbert, while the lowest from the irrigated plat is 562 quarts, for Marlboro, and the highest is 1,485 quarts, for Cuthbert. In 1899 irrigation was effective in four out of the six cases, though in no case was the advantage from irrigation as great as in 1898, nor were the variations in yield as marked as in

400 feet 2½-inch wrought-iron pipe, tees, laying, and painting	$45
Condemned fire hose, 900 feet, with connections, price not constant (approximately)	36
Building for engine, trench for leading water to pump, various arrangements for distributing water, etc. (approximately)......	40
Total	329

PLANT OF W. P. STOKES, MOORESTOWN, N. J.

Mr. Stokes erected an irrigation plant early in 1899. He uses a 2½-horsepower gasoline engine, a single-acting force pump (cylinder 6 by 12 inches). His source of supply is three driven wells, with 2-inch pipe. These three driven wells are connected and the pump draws from all three at once; a flow of 50 to 60 gallons per minute being secured, although the wells would yield a great deal more. Before putting down the drive wells, an open well 15 feet deep and 8 feet in diameter was dug and bricked. Considerable trouble was

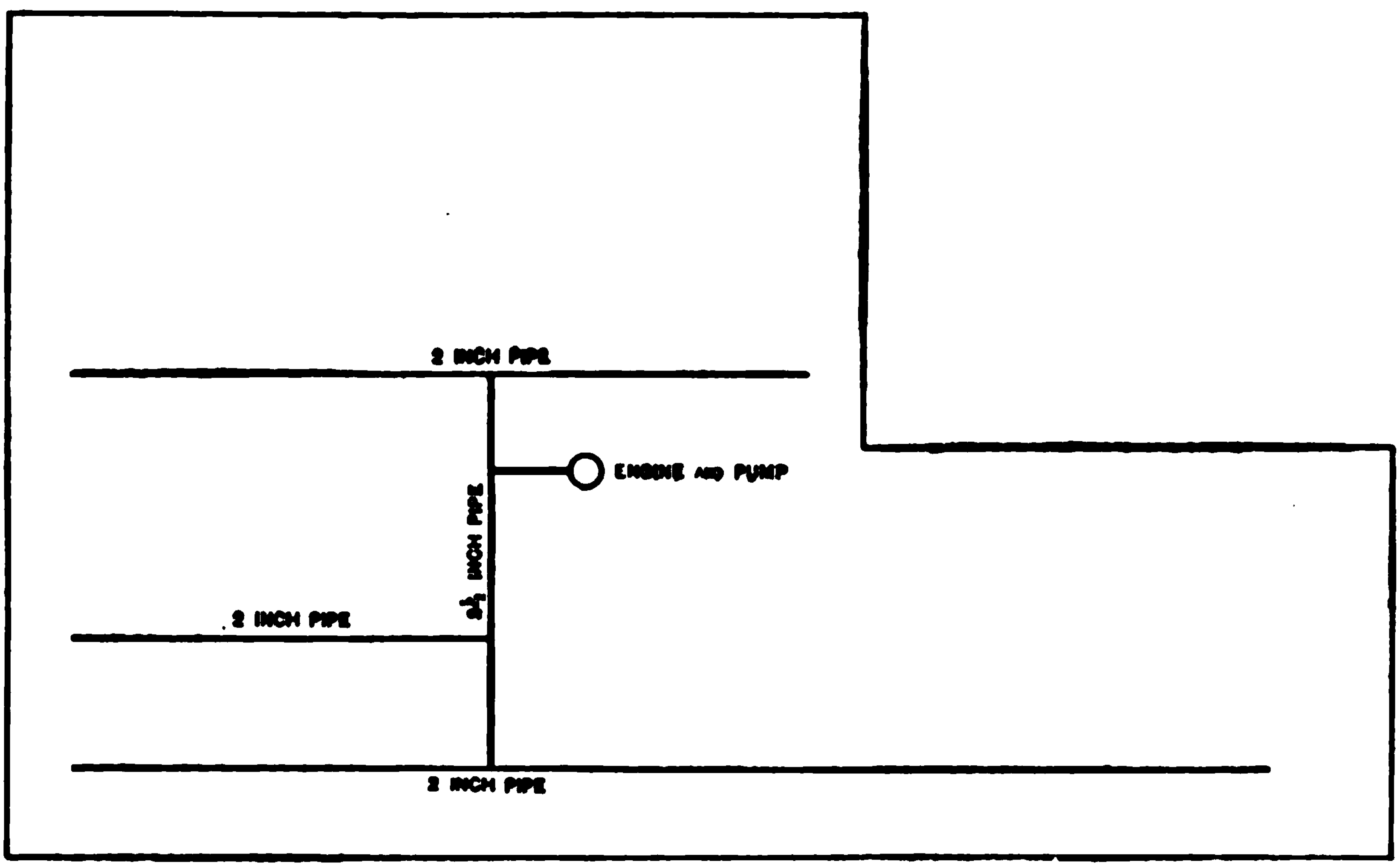

FIG. 3.—Plan of irrigation plant of W. P. Stokes.

experienced on account of the well caving in while being dug. The chief object of digging the well was to remove a bed of clay that might make the driving very difficult. The three wells were driven from the bottom of the open well as far distant from each other as the diameter of the well would permit. The working heads and cylinder of the pump were put as near the bottom of the well as possible. The combination countershaft for the belting from the engine and for working the pump was at the top of the open well. The engine is placed at the usual distance from countershaft, i. e., 10 feet om pulleys. The engine is set on a brick foun- hrough distributing mains. The system

the farm. The main is permanent, but the side lines are laid down when irrigation is wanted. The T's used in the main hose for connecting with the side lines are made from stovepipe riveted together and dipped in coal tar and oil. They use, altogether, 2,800 feet of hose. They use two distributers similar to the one used by Mr. Mitchell.

COST OF PLANT.

The total cost of this plant, not including labor performed by Scribner Brothers, was approximately $400. The chief items of expense were as follows:

Chief items in cost of Scribner Brothers' plant.

Engine and pump erected, with suction and discharge pipe	$200.00
Pond	5.50
Building 6 by 14 feet	7.00
Hose and connections	92.50
Troughs	45.00
Labor (estimated)	40.00
Total	390.00

If the pump is kept going ten hours per day, six days in the week, 1 inch of water could be put on 25 acres each week. It would not be advisable to calculate on watering that acreage, however, as it is best to have a larger plant, so as to allow for some hindrances. The Scribner Brothers' soil is gravelly to sandy loam. It costs them, to distribute the water, 75 cents per day, besides the time of four men on small plants and two men on large vegetables or trees.

Scribner Brothers have irrigated about six acres of crops, as follows: Tomatoes, cabbage, cauliflower, beets, carrots, radishes, potatoes, corn, strawberries, blackberries, raspberries, asparagus, celery, onions, lettuce, parsnips, salsify, rhubarb, parsley, and some other crops. They do not use less than 2 inches of water at each irrigation, and from that up to 4 inches. Four inches was put on berries of the bush variety. They report that irrigation this year has paid on all crops to nearly the extent of the cost of the plant.

PLANT OF HON. J. J. GARDNER, EGG HARBOR, N. J.

This plant was erected during the summer of 1899. It consists of an engine and pump like those used by George A. Mitchell and Scribner Brothers. The water is secured from a large open well, 12 by 12 feet. This well was dug by making a large curb of inch boards that would settle as fast as the bottom was dug out. After getting down 10 feet there was a great deal of fine clay. This was taken out by ...ring the bottom and pumping out the muddy water with the cen...mp. The engine and pump are capable of drawing from ...lons of water per minute, but the capacity of the well at ...t is about 500 gallons per hour.

result in securing a paying crop, the increase would be likely to be proportionately greater on soils of good character.

One acre of cantaloups, one-half acre of early cabbage, one-quarter acre of onions, about one-eighth acre each of sowed corn, sweet corn, sweet potatoes, Lima beans, and white potatoes, followed by Hubbard squash, and one-sixteenth acre each of watermelons, cucumbers, tomatoes, and carrots were raised.

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Irrigated.

Plat 1.—Stable manure only.
Plat 2.—Stable manure, plus 150 pounds nitrate of soda per acre.

Unirrigated.

Plat 3.—Stable manure only.
Plat 4.—Stable manure, plus 150 pounds of nitrate of soda per acre.

Irrigated.

Plat 5.—Minerals,[1] plus 150 pounds nitrate of soda per acre.
Plat 6.—Minerals, plus 250 pounds nitrate of soda per acre.

Unirrigated.

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CANTALOUPS.

The nitrate of soda was applied in three equal applications: The first in a broad circle about the hill, May 6; the second in the same way, June 9; and the last was applied broadcast, June 22.

The experiment with cantaloups, while showing the superiority of irrigation on plats treated with yard manure over those treated with minerals and nitrate, was a practical failure, owing to the blight of the vines early in the season of picking.

EARLY JERSEY WAKEFIELD CABBAGE.

A red clover sod was plowed under in 1898 on the half acre used for cabbage. The same number of cabbage plants were set out on each plat at each setting—March 27, April 6, 10, and 19. Resetting was as follows:

	Apr. 27.	May 9.
Plat 1	27	13
Plat 2	28	15
Plat 3	34	14
Plat 4	44	19
Plat 5	48	19
Plat 6	46	31
Plat 7	27	20
Plat 8	33	23

[1] By minerals is meant not less than 60 pounds of available phosphoric acid and 100 pounds of actual potash per acre.

injured by sun scald. The yields for the two years on plats No. 1 and No. 2, and the averages for all plats, are given in the following tables:

Total yields of gooseberries per acre on irrigated and unirrigated plats, 1898 and 1899.

Variety.	1898. Plat 1.	1898. Plat 2.	1899. Plat 1.	1899. Plat 2.
	Quarts.	*Quarts.*	*Quarts.*	*Quarts.*
Downing:				
Irrigated	2,988	2,292	6,756	6,216
Unirrigated	1,776	1,824	8,268	4,116
Gain from irrigation	1,212	468	—1,512	2,100
Columbus:				
Irrigated	738	84	2,592	1,272
Unirrigated	240	96	3,396	1,656
Gain from irrigation	498	— 12	— 804	—384
Houghton:				
Irrigated	7,588	3,708	9,024	8,748
Unirrigated	6,138	4,344	9,732	5,736
Gain from irrigation	1,450	—636	— 708	3,012
Triumph:				
Irrigated	252	72	1,548	552
Unirrigated	210	192	2,952	1,886
Gain from irrigation	42	—120	—1,404	—1,334

Average yields of gooseberries per acre on all the plats for 1898 and 1899.

Variety.	Irrigated.	Unirrigated.	Gain from irrigation.	
	Quarts.	*Quarts.*	*Quarts.*	*Per cent.*
Downing:				
1898	2,192	1,640	552	33.7
1899	6,140	6,668	— 528	....
1898–99	4,166	4,154	12	.3
Columbus				
1898	522	250	272	108.8
1899	2,376	2,592	216	....
1898–99	1,449	1,421	28	1.97
Houghton				
1898	5,325	5,302	23	.43
1899	8,768	7,784	984	12.6
1898–99	7,046	6,543	503	7.7
Triumph:				
1898	198	230	— 32	....
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1898–99	687	1,391	— 704	....

IRRIGATION OF VARIOUS CROPS BY GEORGE A. MITCHELL, VINELAND, N. J.

The crops noted below were grown with and without irrigation, and special care was taken to treat the irrigated and nonirrigated plats exactly alike. The soil used was a light sand, and though naturally well adapted to the growth of vegetable crops, was deficient in fertilizing elements and was in poor physical condition. It was, however, uniform in character and well suited to the purpose of testing the advantage of an abundant water supply, since, if water would here

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